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GEOLOGICAL SURVEY RESEARCH 1972

Chapter A

GEOLOGICAL SURVEY PROFESSIONAL PAPER 800–A

GEOLOGICAL SURVEY RESEARCH 1972

GEOLOGICAL SURVEY PROFESSIONAL PAPER 800

Significant results of investigations for fiscal year 1972, accompanied by short papers in the fields of geology, hydrology, and related sciences. Published separately as chapters A, B, C, and D

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1972

UNITED STATES DEPARTMENT OF THE INTERIOR

ROGERS C. B. MORTON, Secretary

GEOLOGICAL SURVEY

V. E. McKelvey, Director

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GEOLOGICAL SURVEY RESEARCH 1972

Chapter A

GEOLOGICAL SURVEY PROFESSIONAL PAPER 800–A

A summary of recent significant scientific and economic results accompanied by a list of geologic and hydrologic investigations in progress and a report on the status of topographic mapping

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1972

UNITED STATES DEPARTMENT OF THE INTERIOR

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FOREWORD

"Geological Survey Research 1972," the 13th annual review of the economic and scientific work of the U.S. Geological Survey, consists of four chapters (A through D) of Professional Paper 800. Chapter A summarizes significant results, and the remaining chapters consist of collections of short technical papers. As in the past the purpose of the volume is to make available promptly to the public many of the highlights of Survey research and investigations.

Some, but not all, of the results summarized in chapter A are discussed in more detail in the short technical papers of chapters B through D or in reports listed in "References Cited." The tables of contents for chapters B through D are listed on pages A293–A298 of this chapter.

Numerous Federal, State, county, and local agencies and other organizations and countries listed on pages A245–A251 made significant financial contributions to the results reported here. They are identified where appropriate in the short technical papers (chapters B–D) and in papers published cooperatively but are not generally identified in the summary statements of chapter A. If a summary statement is the result of collaboration with a colleague from outside the Survey, however, the colleague's current organization (such as a university) is indicated in parentheses immediately following his name in the text.

Previous volumes of the annual review are listed below with their series designations.

Geological Survey Research	Prof. Paper
1960	400
1961	424
1962	450
1963	475
1964	501
1965	525
1966	550
1967	575
1968	600
1969	650
1970	700
1971	750

Next year the significant results of research, now in chapter A, will be published alone in Professional Paper 850 entitled "Geological Survey Research 1973." The short technical papers, currently published in chapters B through D, will be published in six issues of a new periodical entitled "Journal of Research of the U.S. Geological Survey."

V. E. McKelvey,
Director.

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REFERENCES

Text references are in two forms:

Harry Klemic and M. E. Mrose (p. C53—C62)

Refers to a short paper published in a chapter of "Geological Survey Research 1972." The letter preceding the page numbers identifies the chapter. The tables of contents for the short-paper chapters are on p. A293—A298.

L. J. P. Muffler and D. E. White (1972)

Refers to a publication listed in "References Cited" on p. A235—A243.

ABBREVIATIONS

[Singular and plural forms for abbreviations of units of measure are the same]

A ..... angstroms
acre-ft ..... acre-feet
ADP ..... automatic data processing
atm ..... atmosphere
bgd ..... billion gallons per day
BOD ..... biochemical oxygen demand
B.P. ..... before present
b.y. ..... billion years
cal ..... calories
cfs ..... cubic feet per second
Ci ..... curies
cm ..... centimeters
COD ..... chemical oxygen demand
CRT ..... cathode ray tube
cu ft ..... cubic feet
cu mi ..... cubic miles
cu yd ..... cubic yards
d-c ..... direct-current
DDD ..... dichloro-diphenyl-dichloro-ethane
DDE ..... dichloro-diphenyl-dichloro-ethylene
DDT ..... dichloro-diphenyl-trichloro-ethane
DO ..... dissolved oxygen
DSDP ..... Deep Sea Drilling Project
Eh ..... oxidation-reduction potential
emu ..... electromagnetic units
EROS ..... Earth Resources Observation Systems
ERS ..... Earth Resources System
ERTS ..... Earth Resources Technology Satellite
eU ..... equivalent uranium
F.L. ..... focal length
fph ..... feet per hour
fps ..... feet per second
ft ..... feet
g ..... grams
G° ..... standard state Gibbs free energy
gal ..... gallons
G.m.t. ..... Greenwich mean time
GOES ..... Geostationary Operational Environmental Satellite
gpd ..... gallons per day
gpm ..... gallons per minute
γ ..... photon
hfu ..... heat-flow units
hr ..... hours
Hz ..... hertz
IDOE ..... International Decade of Ocean Exploration
IHD ..... International Hydrological Decade
in. ..... inches
JOIDES ..... Joint Oceanographic Institutions' Deep-Earth Sampling program
kcal ..... kilocalories
kev ..... kiloelectron volts
km ..... kilometers
l ..... liters
lb ..... pounds
M ..... molar
m ..... meters
m ..... molal
MCi ..... megacuries
Mev ..... million electron volts
mg ..... milligrams
mgal ..... milligals
mgd ..... million gallons per day
mi ..... miles
min ..... minutes
MSS ..... multispectral scanner
mv ..... millivolts
m.y. ..... million years
μ ..... microns
μcal ..... microcalories
μg ..... micrograms
μm ..... micrometers
μmhos ..... micromhos
n ..... neutrons
NASA ..... National Aeronautics and Space Administration
nm ..... nanometers
NMAS ..... National Map Accuracy Standards
NTIS ..... National Technical Information Service
nvt ..... integrated neutron flux
OAS ..... Organization of American States
ohm-m ..... ohm-meters
oz ..... ounce
p ..... proton
PCB ..... polychlorinated biphenyls
pCi ..... picocuries
PDB ..... Pee Dee Belemnite standard
pH ..... measure of hydrogen ion activity
ppb ..... parts per billion
ppm ..... parts per million
psi ..... pounds per square inch
RBV ..... return beam vidicon
SCS ..... Soil Conservation Service
sec ..... seconds
SEOS ..... Synchronous Earth Observatory Satellite
SMS ..... Synchronous Meteorological Satellite
sq mi ..... square miles
$s_{\bar{x}}$ ..... standard error of laboratory means
T ..... recurrence interval
TVA ..... Tennessee Valley Authority
USAF ..... U.S. Air Force
USAID ..... U.S. Agency for International Development
USBM ..... U.S. Bureau of Mines
USGS ..... U.S. Geological Survey
USPHS ..... U.S. Public Health Service
UTM ..... Universal Transverse Mercator
VLF ..... very low frequency
WHOI ..... Woods Hole Oceanographic Institution
yr ..... years
‰ ..... per mil

RESOURCES INVESTIGATIONS

The U.S. Geological Survey carries out broad and highly diversified research programs to increase our understanding and to aid in our management of the mineral, energy, and water-resources potential of the land area of the United States and of the mineral resources of the adjacent continental margins. These programs play a vital role in furthering the Nation's development, as they provide basic information on the character, magnitude, location, and distribution of mineral and water resources, as well as on the principles and processes involved in their formation. This information provides a basis for many critical decisions and actions including location and development of mineral deposits, utilization of water resources, land management and use, urban planning and development, construction practices, and environmental and health problems. Highlights of the Geological Survey's investigations during fiscal year 1972 are summarized in this volume.

SPECIAL AND TOPICAL MINERAL-RESOURCE PROGRAMS

The mineral-resource programs of the Geological Survey focus on the solution of problems related to supplies of mineral raw materials and to the management of domestic resources. The programs comprise wide-ranging investigations pertaining to the origin, occurrence, and distribution of energy and nonenergy minerals and mineral raw materials in nature, to the development and improvement of mineral exploration concepts and techniques for locating new deposits of minerals, and to the evaluation of the known and potential mineral resources of the Nation. Important developments and highlights of these programs are summarized in this section; many other results are included in the section "Geological, Geophysical, and Mineral-Resource Studies."

Other special activities carried out by the Geological Survey in the mineral resource field include (1) mineral surveys of areas under consideration for inclusion in the National Wilderness Preservation System and (2) financial assistance, through the Office of Minerals Exploration, to private industry to stimulate exploration for certain mineral commodities.

BASE, FERROUS, AND PRECIOUS METALS

SUBDUCTION AND MINERALIZATION

The proximity of post-Eocene metallogenic provinces to boundaries of lithospheric plates has been noted by P. W. Guild (1972b) as supporting evidence for the genetic relationship between mineralization and subduction. Most provinces are near the margin of a continental block or in a volcanic island arc above Benioff seismic zones, the youngest provinces being 100 to 200 km above the Benioff zone as determined from earthquake foci. Partial fusion of the descending plate at these depths may produce the calc-alkaline magmas that rise to form the igneous rocks with which many ores are associated. Seismic contour maps thus may provide clues to areas where mineralization may be active but not yet exposed; conversely, ore provinces may be evidence of former subduction.

Guild further noted (1972a) that massive sulfide and porphyry copper-molybdenum deposits are types that occur near consuming margins of lithospheric plates. The stratabound massive sulfide deposits of volcanic affinities formed in island arcs nearly contemporaneously with the enclosing rocks; they are present in rocks ranging in age from Precambrian to at least Tertiary and may be forming today. Orogeny and subsequent deep burial have preserved many of the older deposits from erosion. Porphyry deposits occur in at least four environments that range from simple island arcs to reactivated continental platforms. Most porphyry deposits are Mesozoic or Tertiary in age; syn- or post-orogenic emplacement high in the crust facilitated erosion and probably accounts for the relative scarcity of pre-Mesozoic deposits.

ZINC, COPPER, AND LEAD

Formation of the enigmatic east Tennessee zinc ores

Edwin Roedder (1971a) has studied a large number of fluid inclusions in samples of ore and gangue minerals from five active mines in the east Tennessee zinc district and from many

similar but smaller deposits in the area. These studies show that ore formed from a hot (80°–150°C), dense, saline brine (mostly more than 20 weight-percent salts). The data are important because they place severe restrictions on possible modes of origin; deeply circulating dense connate brines were the most probable ore fluids. These fluids have presumably moved through a pre-established paleoaquifer system created by circulating ground water.

Form of copper and zinc deposits in the upper Mississippi Valley district

A. V. Heyl and W. S. West report that carbonate strata of the Decorah Formation were dolomitized long prior to mineralization in an area of recent zinc mining east of Mineral Point, Wis. Sphalerite ore replaces the dolomite but also fills thin veins that are vertical, inclined, or parallel to the horizontal bedding. Well-formed "pitches and flats" are absent. The zinc ore body is controlled by weak vertical intersecting fractures that have east and southeast trends. Leaching, prior to and during mineralization, made the beds more spongy and permeable, but the thinning and sagging of dolomite strata seen elsewhere in the district are imperceptible east of Mineral Point. In places, veins of late-stage massive chalcopyrite, pyrite, and marcasite without sphalerite or galena cut vertically across zinc ore bodies into the Galena Dolomite above and locally form lenses along bedding. These veins also contain cobalt, nickel, and arsenic-bearing minerals, some of which have not been previously reported from the district. Certain beds in the lower and middle parts of the Galena Dolomite were selectively leached by ore solutions into spongelike masses in which vuggy chalcopyrite and lesser bornite were deposited along with pyrite and marcasite, but without sphalerite and galena, although locally copper-arsenic-cobalt minerals coat sphalerite and galena. Copper-cobalt-arsenic minerals apparently were deposited in and near minor joints at a late stage of ore deposition after the main sphalerite and galena mineralization had ceased.

Suggested source of radiogenic lead in the upper Mississippi Valley zinc-lead district

Studies of wavellite from marine phosphatic zones in Upper Cambrian sandstones of Jackson County, Wis., by Harry Klemic and M. E. Mrose (p. C53–C62) suggest a relationship between the wavellite and primary uranium and thorium in the phosphatic zones. Marine phosphate deposits commonly contain minor amounts of uranium, thorium, and rare earths. Those in Wisconsin contain rare earths but are only weakly radioactive. They were extensively leached and eroded after uplift of the Wisconsin dome. The enclosing formations are aquifers, dip southward off the dome, and extend beneath the upper Mississippi Valley zinc-lead district. Galena lead in that district is increasingly radiogenic to the northeast, and a northeastern source has previously been postulated. It is here suggested that the radiogenic lead formed from primary uranium and thorium in Paleozoic marine phosphorites prior to postuplift leaching and erosion of the sandstones on the flanks of the dome.

Geochemical sampling in Wisconsin

Stream-sediment samples collected in parts of the Wisconsin zinc-lead district by W. S. West and Helmuth Wedow, Jr., were analyzed spectrographically for 30 elements including copper and lead and chemically for zinc, mercury, arsenic, and combined heavy metals. This reconnaissance sampling clearly showed the presence of the zinc-lead-copper ore body of Grayville No. 2 mine and several known copper deposits east of Mineral Point; zinc anomalies found by J. G. De Geoffroy (1969) in spring water east of Livingston and north of Mineral Point were verified. A zinc anomaly reported by De Geoffroy southwest of Argyle was not verified.

Other results of this preliminary sampling are: (1) Elements other than zinc, lead, and copper also appear to indicate proximity to ore deposit, and (2) anomalous samples derived by surface runoff occur near the heads of gullies far upstream from the highest spring flow.

SULFIDE MINERALIZATION

Northern Shoshone Range, Nevada

Sulfide mineralization in the Lewis, Hilltop, and Bullion mining districts, northern Shoshone Range, Nev., conveniently fits a twofold classification scheme according to T. J. Armbrustmacher. The earlier base and ferrous metal sulfides, including arsenopyrite, pyrite, chalcopyrite, rare pyrrhotite, sphalerite, and galena, form one sequence. A later sequence consists of antimony-rich copper, lead, and silver sulfosalts, such as tetrahedrite, bournonite, boulangerite, miargyrite, pyrargyrite, stibioluzonite, owyheeite(?), jamesonite, stibnite, stannite, and native gold. All these minerals are not present in every deposit, and the mineral sequence of each deposit may differ in detail, but the age relationships of the groups agree with previous paragenetic models.

Reinterpretation of the origin of massive sulfide deposits at Jerome, Arizona

C. A. Anderson and J. T. Nash (1972) have reinterpreted the massive sulfide copper-bearing deposits at Jerome, Ariz., to be primarily strata-bound lenses occurring in Precambrian massive quartz-bearing crystal tuffs and overlying bedded tuffaceous rocks. The crystal tuffs were emplaced as submarine pyroclastic flows, and the massive sulfide lenses are chiefly syngenetic, formed by hydrothermal brines that discharged into a submarine basin. The host rocks and sulfide lenses were folded and mildly metamorphosed, and during a second period of folding along vertical axes some of the chalcopyrite in the

major lens of the deposit was transported vertically downward (metamorphic mobilization) to form ore shoots at vein intersections in crystal tuff and chloritized tuff.

FLUID INCLUSIONS

Detailed studies of fluid inclusions in samples from the copper deposit at Bingham, Utah, were made by Edwin Roedder, (1971b) as part of a larger study by the U.S. Geological Survey. Similar but less detailed studies were made at Climax, Colo.; Butte, Mont.; and other deposits. The most significant finding is that unusual fluids that presumably brought in the ore metals were very hot (up to 700°C.) in the central or core areas of the porphyry copper deposits at Bingham and were extremely saline (more than 60 weight-percent salt in solution). Inclusions in the peripheral lead-zinc deposits were much cooler and much less saline. This general picture has since been corroborated in other deposits by other workers, and the knowledge could become a useful tool for exploration of porphyry copper deposits.

GEOCHEMICAL PROSPECTING FOR BRECCIA PIPES, SAN JUAN MOUNTAINS, COLORADO

Geochemical anomalies associated with the upper Tertiary breccia pipes in the northwest San Juan Mountains, Colo., provide useful prospecting guides, according to F. S. Fisher (1972). Highly altered rocks in the central parts of the pipes have been extensively leached of aluminum, magnesium, calcium, sodium, and potassium and consist mainly of porous masses of quartz. Moderately altered and leached rocks adjacent to the porous quartzose zones are composed of abundant clay minerals and lesser amounts of quartz, alunite, and pyrophyllite. The outermost zones of the pipes are characterized by fine-grained micaceous minerals, quartz, and pyrite and are depleted of calcium and magnesium. Sulfide minerals associated with the pipes have high ratios of sulfur to metal and consist of silver-bearing copper and lead sulfosalts of arsenic and antimony and common base-metal sulfides. Silver, arsenic, gold, bismuth, lead, and antimony are probably the most useful elements for geochemical prospecting for new breccia-pipe targets in the area.

IRON

Mafic complex at Lake Owen, Medicine Bow Mountains, Wyoming

The mafic complex at Lake Owen in the southeastern Medicine Bow Mountains of Wyoming is described by R. S. Houston as a cup-shaped layered complex of late Precambrian age that is tilted to the northeast about 60°. Consequently, a nearly horizontal cross section through layered rock is exposed in an area about 7 mi in length and 5 mi in width. Like many similar mafic bodies elsewhere, this complex has primary sedimentation features that resulted from convective overturn and crystal settling. This mechanism caused the development of layers that are rich in heavy minerals of economic value, such as magnetite. Four magnetite-rich zones have been recognized; one extends for over 2 miles which is as far as current mapping has been completed. The Lake Owen mafic complex is in an area where mafic rocks have greater than normal abundances of platinum metals (Theobald, P. K., Jr., and Thompson, C. E., 1968). To date, no platinum-rich horizon has been identified in the Lake Owen mafic complex, but of 109 igneous rocks submitted for analysis, 24 contained detectable platinum (average 22 ppb, range 5–150 ppb) and 48 contained detectable palladium (average 2 ppb, range 2–150 ppb).

Ore deposition at Creede, Colorado

The continuing study of the Creede deposit in Colorado by P. M. Bethke and P. B. Barton, Jr., has revealed variations of the iron content of sphalerite deposited with pyrite and (or) hematite or chlorite. The variations suggest that the ore-forming environment behaved as a chemical yo-yo during much of the ore deposition with rapid, but transitory, shifts to much more reduced conditions imposed upon a broad base of relatively oxidized (sulfate-rich) ore fluid. The changes in the mineralogy of the ores must be of deep-seated origin because structures that are hundreds of feet apart vertically show the same sequence. The variation in iron content is tentatively ascribed to pulses of reduced (magmatic?) fluid introduced into a large, convecting body of ore-depositing fluid. The chemical potentials of oxygen and sulfur of the local environment may well have been buffered by chlorite + pyrite + quartz or chlorite + hematite + quartz reactions. Ore mineralogy and textures suggest that the sulfate and sulfide in the mixed fluid reached redox equilibrium only slowly, if at all.

Iron-formation in Jackson County, Wisconsin

Recent geologic studies by Harry Klemic and age determinations by Z. E. Peterman on granites that intrude the iron-formations and associated rocks of Jackson County, Wis., have indicated that the iron-formation in metamorphosed Precambrian rocks is of Animikie age or older. Rubidium-strontium ratios on the granites give an age of about 1,690 m.y. which places them in the Precambrian X subdivision, 1,600 m.y. to 2,500 m.y.

Magnetic survey and subsurface data obtained from mining companies reveal the presence beneath Upper Cambrian sandstone of widely separated bodies of magnetitic and hematitic iron-formation of currently usable to subeconomic grades.

GOLD

Gold exploration in northern Black Hills, South Dakota

After six field seasons of geochemical sampling in the northern Black Hills, it has become evident to R. W. Bayley (1972) in sampling close to old gold diggings that the principal place for gold to occur is in lean silicated iron-formations, composed of chert-grunerite and garnet; the second most likely place is in quartz veins; and the third is in massive ferruginous chert. Gold in the iron-formations is generally confined to plunging folds that affect the whole formation or to a lesser extent to internal drag folds. Only a few of the formation-size folds have proved barren. Most quartz veins are barren, however, especially those in graywackes, but those close to ore bodies or massive chert, or in graphitic slate, generally contain some gold. The massive chert almost always carries a trace of gold, but of hundreds of samples tested, none is of economic grade. All gold-bearing areas are high in arsenic, which may reach 50,000 ppm. At Rochford, 15 mi south of Lead, Bayley found several minor ore bodies, ranging in grade from $23 to $8.50 per ton.

Sulfide mineralization at Gold Acres, Nevada

Studies by T. J. Armbrustmacher have shown that at the open-pit mine, Gold Acres, Nev., two assemblages of sulfide minerals in tactite and greenstone formed independently of gold mineralization. The older assemblage of pyrrhotite, chalcopyrite, and marcasite is disseminated, whereas the younger assemblage of sphalerite, pyrite, sparse galena and chalcopyrite, together with quartz and calcite, fills veins and partly replaces the older sulfides. Semiquantitative spectrographic analyses of composite samples of the sulfide assemblages contain high concentrations of zinc, cadmium, and manganese and only small amounts of gold and silver. In contrast, the gold ore at the mine contains high concentrations of gold, arsenic, mercury, and tungsten. Besides these differences in trace elements, the distribution of sulfides at the mine is unrelated to rocks rich in gold.

Gold ore in ash-flow cooling units, Thunder Mountain caldera, central Idaho

Additional targets for low-grade gold ore have been identified by B. F. Leonard in rhyolite of the Thunder Mountain district, Valley County, Idaho. The rhyolite contains the Sunnyside mine ore body from which ore containing about 0.18 oz of gold and 0.26 to 0.56 oz of silver per ton was mined during the 1920's and 1930's. The ore body is no longer accessible for direct observation but is interpreted as a blanketlike deposit lying between the welded part of a rhyolite tuff and its nonwelded top. Geologic mapping of complex fault blocks near the Sunnyside mine shows several areas of the same nonwelded part of the tuff, beneath which concealed deposits of ore might be sought. Surface exploration in the district has been confined to faults and, therefore, has not adequately tested intervening ground for stratabound deposits related to cooling units in the pyroclastic filling of the Thunder Mountain caldera.

Gold content of Michigan native copper

Native copper and native silver from the Keweenaw area, Michigan, have been found by P. B. Barton, Jr., and F. O. Simon to carry surprisingly low amounts of gold, in parts per billion. The White Pine copper ores in the Nonesuch Shale, which W. S. White interprets as outflow points for solutions similar to those that mineralized the Keweenawan amygdaloids, are likewise low in gold. Thus, gold appears never to have been present in significant amounts in the ore fluid, or perhaps to have been precipitated prior to and possibly down dip from the copper. In either case, a further study of the gold distribution in the native copper might disclose a gradient in gold content enabling an evaluation of the probability of mineralization at greater depth.

GEOLOGIC EXPLANATION OF OLD MINES AT SILVER CLIFF, COLORADO

Near-surface, silver-rich deposits quarried in the 1880's at Silver Cliff, Colo., have been found by W. N. Sharp, through analysis of recent geologic mapping and surface features, to cap a relatively small diatreme or breccia pipe located at the boundary of a volcanic subsidence block. The breccia pipe and deposits were formed by late-stage volcanic venting. As a result of the recognition of their breccia-pipe character, the Silver Cliff deposits can now be reassessed for mineral potential.

HYDROTHERMAL ALTERATION IN NORTHEASTERN NEVADA

Several square miles of hydrothermally altered limestone, shale, and sandstone occur in the Ferguson Range, north and west of Ferguson in northeastern Nevada, according to A. V. Heyl and C. N. Bozion. The hydrothermal alteration occurs in zones surrounding two small quartz monzonite stocks. Jasperoid and hydrothermally altered and residual shale are widespread and in places contain anomalous quantities of barium, arsenic, copper, tungsten, lead, strontium, silver, lanthanum, antimony, and traces of gold.

LIGHT METALS AND INDUSTRIAL MINERALS

Bauxite on Kauai and Maui, Hawaii

A final report by S. H. Patterson (1971) on bauxite in Hawaii outlines 110 million tons of low-grade ferruginous

bauxite on Kauai that is 25.9 percent Al_2O_3 and 4.7 percent SiO_2 and 31 million tons on Maui that contains 33 percent Al_2O_3 and 6.6 percent SiO_2. In addition to the bauxite, very large potential resources of saprolite containing 27 percent Al_2O_3 and 20 percent SiO_2 occur on these islands. Industrial minerals used on Kauai include crushed basalt, volcanic cinder, beach sand, river sand and gravel, coral, and limestone.

Effects of grinding on quantitative analysis of dawsonite by X-ray diffraction

Studies by E-an Zen and Jane Graham show that X-ray diffraction peak intensities of dawsonite are affected by length of grinding. Using a simple mixture of quartz-dawsonite and a mixture of quartz-dawsonite and typical Green River Formation oil shale, they found that the ratio of the strong dawsonite peak at the 2θ value of 15.5° (Cu radiation) to the quartz peak at 21° may vary erratically by as much as 100 percent for grinding times of 10 to 60 min. Both the peak height and total peak area are affected. The only ratio of peak intensities that is more or less independent of grinding is the dawsonite peak at 32.1° to the quartz peak at 26°. This dawsonite peak, however, is relatively weak and is readily masked by peaks of other minerals.

It is concluded that X-ray diffraction is at best only a fair method to measure the amount of dawsonite and thence to calculate recoverable aluminum in the Green River Formation. The method of direct stepwise leaching and subsequent chemical analysis of leachate is not only more reliable but figures so obtained can be more readily interpreted in terms of industrial assay and sample control.

Fatty acids in bedded barite

Studies of the organic constituents of black bedded barite deposits by R. E. Miller, D. A. Brobst, and P. C. Beck have indicated that the barite contains fatty acids of the types found in the anaerobic sulfate-reducing bacterium *Desulfovibrio desulfuricans*. These acids were found in several samples of fine-grained fetid barite collected from deposits of middle Paleozoic age in Nevada and Arkansas. The presence of the acids suggests that biogeochemical reactions had a role in the formation of barite in sedimentary basins.

Sulfur isotopes in Nevada barite deposits

Robert Rye has analyzed about 30 barite rocks from Nevada and elsewhere for δS^{34} in cooperation with D. R. Shawe, D. A. Brobst, and F. G. Poole to determine the origin of different types of barites in Nevada. The δS^{34} values of massive barites range from +22 to +27°/₀₀. These values are essentially the same as reported for lower Paleozoic evaporite deposits, and they strongly suggest a sedimentary origin for the massive bedded barite in Nevada. On the other hand, hydrothermal barite occurring in cross-cutting veins in Nevada has δS^{34} values ranging from +30 to +50°/₀₀. Bedded barite which has been cut by igneous stocks or has been hydrothermally altered generally has been slightly depleted in δS^{34} suggesting that the bedded barite may be the source of much of the hydrothermal barite. Rosette barite which is often associated with the bedded barite has δS^{34} values ranging from about +38 to +40°/₀₀. These large values may reflect very slow sedimentation rates which allowed bacteria to deplete the sea-water sulfate of δS^{32}. A reconnaissance study of barite deposits from Arkansas and Alaska suggests that sedimentary and hydrothermal barite may be distinguished on the basis of δS^{34} values.

Hydrothermal alteration associated with beryllium deposits at Spor Mountain, Utah

Recent studies by D. A. Lindsey, Harold Ganow, and Wayne Mountjoy show that the beryllium deposits at Spor Mountain occur in water-laid tuff characterized by montmorillonitic and feldspathic alteration. Beryllium ore bodies occur in zones of advanced (feldspathic) alteration where dolomite clasts in tuff have been replaced by silica and fluorite. Extensive zones of lithium-bearing clay and calcite are also present and were formed by less intense alteration (dedolomitization) of clasts. Uranium and manganese minerals also occur locally.

Study of chemical data reveals that alteration was accompanied by addition of Si, Al, H_2O, K, F, and many minor elements and by loss of CO_3^{-2}. Manganese was probably derived by leaching of dolomite clasts in tuff. Reaction of fluorine-rich hydrothermal solutions with carbonate clasts increased the pH of the solutions and triggered widespread feldspathization of the tuff. Increasing pH, decreasing temperature, and decreasing fluorine concentration were variously responsible for the breakdown of stable metal fluoride complex ions and precipitation of beryllium, uranium, and other minerals.

Clay mineralogy of the Green River Formation

Preliminary research by J. W. Hosterman and J. R. Dyni shows that, in the Piceance Basin of northwest Colorado, the fluvial rocks of the upper Wasatch Formation and the fresh-water shales of the Garden Gulch Member of the Green River Formation contain kaolinite, illite, mixed-layer clay, and montmorillonite. The lacustrine oil shales of the Parachute Creek Member of the Green River Formation contain only illite and a minor amount of mixed-layer clay. The tuffaceous sandstone of the Evacuation Creek Member of the Green River Formation contains illite and montmorillonite. The presence of kaolinite in the Garden Gulch Member indicates that it was deposited in an environment containing well-oxygenated fresh water. Its absence in the other two members indicates that they were deposited in reducing anaerobic, brackish to saline, alkaline waters.

Underclay beds in southwest Pennsylvania

The most economically important underclay beds in Somerset, eastern Fayette, and part of Westmoreland Counties, Pa., are the Clarion, Brookville, Lower Kittanning, Upper Kittanning, and Bolivar of the Allegheny Group (Pennsylvanian). According to recent work by J. W. Hosterman (1972), these beds contain flint and semiflint-type clays which are used primarily in making high-grade refractory-clay products. Available evidence suggests that the underclay beds are the result of leaching fine sediments in an acid swamp environment. No evidence was found to support hypotheses of underclay origin based on derivation from soils, residual accumulations resulting from weathering in place, alteration of volcanic ash beds, or accumulation of colloidal matter derived from lateritic weathering.

Potential feldspar resource in Delmarva

Recent mapping by J. P. Owens and others in the Delmarva Peninsula indicates the widespread occurrence of feldspar-rich sands in the Beaverdam Sand of Pleistocene age exposed in Sussex County, Del., and Wicomico and Worcester Counties, Md. The Beaverdam is an eastward thickening light-colored arkosic to subarkosic, fine to coarse marine sand with a known thickness of 80 to 90 ft near the eastern edge of its outcrop. Optical and X-ray studies indicate a feldspar concentration of as much as 50 percent of the sand-size fraction. The feldspar composition is about half plagioclase and half microcline.

Fuller's earth formed in lagoons or tidal flats

Studies by S. H. Patterson of extensive fuller's earth deposits in the Meigs-Attapulgus-Quincy district, Georgia and Florida, show that the deposits formed in the restricted environment of shallow marine lagoons or tidal flats. Fine dolomite crystals with nuclei, filled desiccation cracks, algal heads, and *Calianassa* borings in the fuller's earth indicate the deposits formed in or near the intratidal zone. In the dolomite and palygorskite, the most abundant clay mineral in some deposits, magnesium apparently came from evaporating sea water. Aluminum and silica in palygorskite probably were introduced by streams draining areas where rocks were undergoing intense weathering.

Mercury in phosphate rock in the land-pebble district of Florida

Distribution of mercury in the −200 mesh fraction of a series of stratigraphic samples collected by J. B. Cathcart from a mine in the land-pebble phosphate district indicates that only small quantities of mercury are present. The mercury content of thoroughly leached surface material is very low with an average of about 0.03 ppm. It is highest (as much as 1 ppm) in partly leached material just below and is somewhat enriched (as much as 0.3 ppm) in the uppermost part of the phosphorite that is not obviously leached. It is low (about 0.1 ppm) in the underlying phosphorite. In general, the mercury content of the Hawthorn Formation is somewhat lower than that of the Bone Valley Formation.

Sediments tested for mercury

Samples of sediment from small streams in Kershaw and Lancaster Counties, S.C., collected by Henry Bell 3d (USGS) and A. J. McElveen (Geologic Division, State Development Board) were tested in the field with a mercury vapor detector by A. J. Toevs. Sediment from the Little Lynches River near the Haile gold mine have higher mercury values than samples collected from other nearby streams.

Peat

Reserves of commercial quality moss peat are estimated by C. C. Cameron as 5,100,000 tons, on an air-dried basis, in southeastern Aroostook County, Maine, where potentially exploitable deposits are restricted to raised bogs (heaths) developed on clay in glacial terrane. These deposits combined with those reported last year in Washington County are significant to the eastern Maine peat industry which recently changed methods of mining operation. The introduction of European made clearing and cutting machinery during the past 2 yr near Jonesport is replacing expensive and time-consuming hand labor.

Preliminary study of trace elements in ash analyzed by H. W. Worthing and W. B. Crandell from samples of peat taken also by C. C. Cameron from cores in a bog in the Richfield quadrangle, St. Laurence County, N.Y., reveals rare earths, namely Eu, Nd, Sm, and Dy, associated with anomalous amounts of Zn, Cu, Yb, La, Be, and V. This is one of the few Holocene peat deposits for which trace element determinations have been made.

Bedded salines in lacustrine Tertiary rocks, Uinta basin, Utah

Bedded deposits of sodium carbonate minerals and halite were discovered in a bore hole drilled in late 1970 through the lacustrine Tertiary rocks in the western part of the Uinta basin, about 5 miles north of Duchesne, Utah. A preliminary study of the core by J. R. Dyni has revealed a complex suite of sodium carbonate minerals (wegscheiderite, trona, and nahcolite) and halite in several beds 1 to 12 ft thick at depths of 4,140 to 4,252 ft. Disseminated crystals of northupite, shortite, and citelite were also found in marlstone associated with the salines. Although the bedded salines are too thin and deep for economic development, their discovery increases the possibility of finding commercial deposits elsewhere in the Uinta basin.

Trona resources of Wyoming updated

A 1966 estimate of trona resources of the Green River basin of Wyoming was recently updated by W. C. Culbertson (1972). Trona (sodium sesquicarbonate) is a major source of the industrial chemical soda ash and is presently mined at four localities west of Green River, Wyo. Abundant, but still incomplete, data indicate that the Wilkins Peak Member of the Green River Formation contains about 100 billion tons of trona and halite in beds as much as 40 ft thick. Approximately 10 to 15 percent of this is halite (NaCl), which occurs in 14 beds. Most of the halite is intermixed or interlayered with trona, but some is in virtually pure halite beds. About 30 to 40 billion tons of trona is considered favorable for recovery in the near future and is here defined as halite-free trona in beds more than 6 ft thick underlying an area of more than 25 sq mi.

Sulfur mineralization, Gulf Coast

A. J. Bodenlos notes that alteration of anhydrite to calcite and sulfur in Gulf Coast salt-dome caprocks took place in an oxygen-deficient environment. It seems likely that hydrogen sulfide escaped upward during initial stages while medium-grained calcium carbonate was being precipitated. The system must have been closed during a second stage when coarse-grained calcite and elemental sulfur were being precipitated together.

It has been suggested that hydrogen sulfide is converted to elemental sulfur by oxygen carried downward in ground water, but Gulf Coast ground water is deficient in oxygen. The most likely chemical reaction producing elemental sulfur thus appears to be between hydrogen sulfide and calcium sulfate, which would produce both the sulfur and the second-generation coarse-grained calcite.

Ilmenite in alluvium near Roseland, Virginia

Sampling of river terraces and bars northeast and southwest of the Roseland, Va., rutile district, by J. P. Minard and G. W. Hayes indicates that large volumes of ilmenite-rich alluvium are present in the valley bottoms. Ilmenite values in the Rockfish drainage range from 2 to 4 percent in auger samples from the broad alluvial valley fill. Values as high as 28 percent ilmenite were found in samples from auger holes in the valley fill; horizontal channel samples across transverse, longitudinal, and point bars: vertical channel samples from alluvium in stream banks; and rocks from outcrops in upper Buffalo River drainage.

Geophysical-geological reconnaissance for vermiculite

The problem of finding deposits of vermiculite in the deeply weathered terrain of the inner Piedmont region of northwestern South Carolina may be eased by a combined geophysical-geological reconnaissance according to A. L. Bush. The host rocks for vermiculite in the area generally are dominantly elongate, somewhat layered, ultramafic bodies within which surficial alteration has formed irregular, lenticular vermiculite masses. Host rock masses are as much as a few thousand feet in length and a few hundred feet in width; their depth is not known. Vermiculite bodies are commonly nearly as large as the host rock masses in horizontal extent, but they are rarely as much as 80 ft thick. Significant magnetic anomalies attributable to ultramafic bodies in Virginia and North Carolina suggest that the host rocks in the vermiculite region of South Carolina might be identifiable by airborne geomagnetic reconnaissance and that surface geologic and geophysical techniques might then be profitably applied to locate and outline vermiculite concentrations in the ultramafic bodies.

Nearly pure zeolite in McMullen County, Texas

A bed of nearly pure zeolite of undetermined thickness and areal extent has been discovered by K. A. Dickinson in McMullen County, Tex., near the village of Tilden. Previously reported concentrations of zeolite in the area are opalized and are less pure.

Additional zeolite deposits in Arizona

Through X-ray studies of 31 samples of rhyolite tuff from the Ray-San Manuel area, Pinal County, Ariz., M. H. Krieger finds that clinoptilolite is abundant in some beds and absent in others. This mineral is a major constituent of rhyolite tuff beds of Oligocene and early Miocene age and, with one exception, is absent or essentially absent in younger beds. These occurrences are in addition to those described recently by R. A. Sheppard (1971).

RADIOACTIVE MATERIALS

THORIUM

High-grade thorium veins in northern Idaho

Unusually high-grade thorium veins occur in an area of about half a square mile on Hall Mountain in northernmost Idaho (Staatz, M. H., 1972). These veins, which cut the Prichard Formation of the Belt Supergroup and quartz diorite Purcell sills, are from 6 to 700 ft long and from a fraction of an inch to 19 ft thick. The thorium content of 23 samples collected by M. H. Staatz from 11 veins ranged from 0.0095 to 21.0 percent. Twelve samples had a thorium content of more than 1 percent. The thorium and the mineral contents of the veins are erratic, varying both among the veins and within an individual vein. Thorite is the principal thorium mineral; allanite is also fairly common. As these veins are coarser grained and contain less iron oxides than most thorite veins in

other districts, the thorite will be easier to separate from the gangue.

URANIUM

Geologic aids in exploring for sandstone-type uranium deposits

As knowledge of the Gas Hills and other structurally uncomplicated sandstone-type uranium districts has grown, certain features have been recognized that, according to F. C. Armstrong, will promote a better understanding of known districts and may prove useful in the search for new ones. First, in structurally uncomplicated areas it has been postulated that the mineralizing solutions flowed down the regional dip of the sandstone beds and that depth of penetration of the solutions varied greatly along strike. A corollary of this direction of flow is that altered sandstone extends from the unaltered-altered interface updip to the outcrop or to the suboutcrop of the sandstone beneath an unconformity.

Secondly, it has been reasonably well demonstrated, largely as the result of unpublished work by J. N. Rosholt and Z. E. Peterman, that a granitic terrane, the Granite Mountains, can and probably did supply most of the uranium to the sandstone deposits found in the surrounding depositional basins. From this it may be concluded that sandstones in heterogeneous detrital wedges along margins of intermontane basins that are flanked by granitic terranes are potential hosts for uranium deposits.

Consequently, it is evident that a knowledge of the detailed geologic history of a basin and its adjacent highlands can be a powerful tool in choosing areas to explore. To permit uranium deposits to form, the granitic terrane must be exposed to erosion and must be supplying uranium to groundwater at a time when the groundwater has access to sandstones in the basin that extend downdip into a reducing environment.

Stratigraphic and petrographic studies of Tertiary rocks in the Powder River Basin, Wyoming

According to N. M. Denson and G. H. Horn, regional mapping throughout large areas in the Powder River Basin of eastern Wyoming indicates that the important uranium deposits in the basin occur in the lower part of the Wasatch Formation (lower Eocene) which at most places rests with angular discordance on the Lebo Shale and Tongue River Members of the Fort Union Formation (Paleocene). Although some of the important deposits in the basin are considered by some to occur in the Fort Union, areal mapping indicates that these deposits rightly should be assigned to the Wasatch Formation. The contact between the Fort Union and Wasatch Formations is at some localities indefinitely known; at most localities, however, an unconformity and conspicuous lithologic and mineralogic differences are observable at the boundary.

Rocks of early Eocene age are composed mostly of first-cycle sediments derived largely from the Precambrian cores of the mountains and are host to some of the largest uranium deposits in the Rocky Mountain region. They generally are coarser grained, more poorly sorted, and are lighter in overall appearance than those of Paleocene age which generally are composed of second- and third-cycle sediments derived largely from the erosion of Paleozoic and Mesozoic rocks. Although in some areas in the Powder River Basin, a particular coal bed may coincide with the Fort Union-Wasatch boundary, a distinct lithologic and mineralogic break is a more reliable criterion in selecting the contact.

The nonopaque heavy minerals from the very fine grained sand fraction in representative samples collected from the Wasatch are characterized by the abundance of either blue-green hornblende, epidote, garnet, or any combination of the three; whereas in general the dominant heavy minerals from the Fort Union Formation are tourmaline and the pinkish-violet plutonic variety of zircon. Rutile and staurolite are important accessory minerals which aid in identifying Fort Union assemblages. Not only are the percentages of the various heavy-mineral species different, but the abundance of heavy minerals in the Wasatch Formation is generally three or more times than that in the underlying Fort Union.

Types of uranium deposits in south Texas

The most recently discovered deposits of uranium in south Texas suggest to D. H. Eargle the following reclassification of uranium deposits in this area into four types, according to type of occurrence and locale of deposition:

1. At margins of stream channels or large alluvial systems and in porous sands interbedded with clays or silts of lower porosity.
2. In porous beds beneath stream channels at the base of unconformably overlying deposits. This occurrence suggests a chemical sump where a prevailing reducing environment changes the chemistry of the uranyl compounds in solution and causes their deposition.
3. In the vicinity of faults where hydrogen sulfide or other reducing agents are in constant supply.
4. In porous sands and beneath less porous beds overlying salt domes where sulfurous gases are concentrated.

Altered sandstone as an exploration guide

According to E. N. Harshman, analytical data and heavy mineral studies on suites of samples from uranium deposits in the Wyoming basins, Black Hills of South Dakota and Wyoming, and Texas Coastal Plain show that the individual deposits were formed by geochemical processes that were similar in many aspects but also differed in some ways. Altered sandstones, genetically related to ore, in the Shirley Basin, Black Hills, and in Karnes County, Tex., are similar in their lack of pyrite and their content of magnetite, goethite,

limonite and (or) hematite. In sharp contrast, the altered sandstones in the Gas Hills and in Live Oak County, Tex., contain considerable pyrite; almost no magnetite; very minor amounts of goethite, limonite, and (or) hematite; and considerable altered feldspar. These differences show that caution must be used in applying many criteria as exploration guides to altered sandstone and ore. New criteria may be required in new districts.

Geologic controls for uranium deposits near Crooks Gap, Wyoming

Geologic mapping by L. J. Schmitt, Jr., in south-central Wyoming near the Crooks Gap uranium-producing district has resulted in recognition of upper and lower parts of the Battle Spring Formation of Eocene age. The two parts were differentiated largely because an intervening angular unconformity was recognized in locally well exposed sections. Further subdivision of the Battle Spring Formation, a time-stratigraphic equivalent of the Wasatch and Green River Formations occurring adjacent to mountain ranges, has been unsuccessful except locally where mappable units may be postdepositional rather than primary sedimentary features. At Crooks Gap only the lower part of the formation has produced significant amounts of uranium although the upper part is well exposed.

The best targets for uranium exploration appear to be in the lower part of the formation where it is proximal to anticlinal folds and where tongues of bleached arkosic sandstone terminate downdip. Exploration is also favorable in the lower part of the formation adjacent to faults associated with the Bare Ring Butte graben.

Worldwide inverse relationship between uranium and gold in ancient pyritic ore conglomerates

By plotting gold tenor against uranium tenor (from production records and ore reserves) W. B. Myers has recognized a reciprocal relationship between the two metals in the Witwatersrand gold field, South Africa. Uranium-gold ratios vary by a factor of more than 600 to form a continuous spectrum of metal values representing all the major reefs.

The reciprocal relationship between the metals is not compatible with a placer origin for the gold but is an expectable consequence of Myers' (1971) recently advanced model genetically linking uranium and gold. It is held that detrital uraninite was shielded from oxidation in the essentially anoxygenic early atmosphere of 2.5 b.y. ago by the abundant and ubiquitous detrital pyrite of the ore beds (which invariably represent surfaces of unconformity). Radioactive decay of uraninite provided an energy flux to precipitate gold which was present in solution as the aurous sulfide complex ion. The metal was reduced by hydrogen released by the radiation polymerization of thucolite from contemporary organic hydrocarbons. A corollary of thucolite formation was the slow dispersal of uranium into the overlying sea water as a soluble carbonate complex. Thus with time an original uraninite-rich placer with a negligible gold content, accumulating on a surface of unconformity, was progressively converted to a gold reef with a moderate to low residual uraninite content, depending on the degree of maturity reached by the hypothetical process.

"Immature" reefs, relatively uranium-rich, tend to be classic, relatively thick, quartz-pebble conglomerates with more or less dispersed metal content. "Mature" reefs, relatively uranium-poor, tend to be of the carbon-seam type, very thin but exceedingly rich in gold.

The average Canadian (Blind River) uranium-bearing conglomerate plots precisely along the gold-poor extension of the South African curve, whereas the Serra de Jacobina conglomerate in Brazil plots at the midpoint of the curve. Published gold values for the ancient pyritic conglomerates of the Krivoi Rog and Kursk Magnetic Anomaly series in the Russian Ukraine suggest that the uranium content, acknowledged as present in detrital uraninite, ranges from 0.1 to 0.2 percent U_3O_8.

ORGANIC FUELS

Coal beds in eastern lower White River coal field, Colorado

Coal beds are present in the vicinity of McAndrews Gulch and Crooked Wash near the White River, Rio Blanco County, Colo., in the upper part of the Williams Fork Formation of Late Cretaceous age, as mapped by W. J. Hail, Jr. The area lies at the extreme eastern margin of the lower White River coal field. Several carbonaceous zones in a nonmarine sequence contain numerous coal beds ranging from less than 1 ft to as much as 6 ft in thickness. The coal beds are highly lenticular and generally nonpersistent.

Paleocene age of the Little Rocky Mountains uplift, Montana

R. F. Marvin and B. C. Hearn, Jr., have obtained three potassium-argon ages of about 60 m.y. on potassium feldspars from quartz monzonite and syenite porphyries exposed in the Little Rocky Mountains, Mont. Intrusion and uplift in Paleocene time shown by this age determination preceded the more widespread middle Eocene igneous activity and uplift in other nearby mountain groups and must have had a significant effect on the early migration and localization of gas and oil in north-central Montana.

Coal resources of a previously unmapped area in northeast Montana

An investigation of the coal resources and Cenozoic geology of the Girard coal field in Richland County, Mont., by G. E. Prichard and E. R. Landis indicates that the field contains more than 5 billion tons of lignitic coal and that one coal bed

in a single township contains estimated measured and indicated reserves in the more than 10-ft-thick category of more than 50 million tons. Much of this coal is overlain by less than 200 ft of overburden.

Faults on the Haystack anticline, Carbon County, Wyoming

The geological investigations of E. A. Merewether (1972) at the Haystack anticline, about 20 km north of Sinclair, Wyo., showed the presence of previously unreported thrust faults and normal faults. Thrust planes crop out near the crest of the anticline and strike northwest and west, approximately parallel to the crestline of the fold. They dip northeast and north. A younger normal fault of large displacement cuts irregularly across the anticline. It probably displaces one of the thrust planes and may have caused a discontinuity in the crestline of the fold. Faulting could be the reason for the lack of success in drilling for oil and natural gas at the Haystack anticline.

Unconformities in the Frontier Formation, northwestern Carbon County, Wyoming

Unconformities found by W. A. Cobban and J. B. Reeside, Jr., in the Frontier Formation near Sinclair, Wyo., in 1951, have now been recognized by E. A. Merewether and W. A. Cobban (p. D57–D66) throughout northwestern Carbon County, Wyo. The unconformities may have importance in the entrapment of oil and gas. Evidence for their location is provided by closely spaced collections of invertebrate index fossils and intraformational changes in the thickness and lithology of the rocks. The lower unconformity seems to be an irregular surface and represents the time interval of most of the Greenhorn Limestone and the lower part of the Carlile Shale of the Black Hills region in Wyoming. The upper unconformity is probably a slightly irregular surface and represents the time interval of a middle part of the Carlile Shale of the Black Hills. The lithology, thickness, and fossils of the Frontier Formation in the southern half of the Rawlins uplift provide sparse evidence of broad folding during deposition of the formation.

Possible economic value of trona-leonardite mixtures

Experiments (Swanson, V. E., and Ging, T. G., 1972) indicate that simple addition of water to mixtures of untreated trona ($Na_2CO_3 \cdot NaHCO_3 \cdot 2H_2O$) and otherwise insoluble leonardite (a naturally weathered, oxidized coal that is readily soluble in alkaline water) yields a rich, black, slightly alkaline solution of concentrated humic substances. The dissolved mixture can be used as (1) a liquid soil conditioner, (2) leaf-spray micronutrient fertilizer with desired chelate elements added, (3) a leach solution for secondary recovery of ore metals, or (4) a substance to capture toxic metals from industrial wastes.

GEOTHERMAL ENERGY RESOURCES

Geothermal energy potential of deep sedimentary basins

The geothermal energy potential of deep sedimentary basins has been examined by B. F. Grossling (1971). In appraising the long-range prospect of geothermal energy, it is necessary to consider these deep basins because of their large masses of stored water and heat. The total amount of energy that can be recovered without regard to costs can surpass, by way of comparison, the heat of combustion of the oil and gas resources of those basins. The bulk of the waters, however, are low in enthalpy (temperature $<150^\circ C$), and only a fraction are high in enthalpy (temperature $>150^\circ C$). The latter may be the more important for electric power generation depending on costs of drilling, power-generation technology, and other factors.

The size of these high-enthalpy hydrothermal resources in sedimentary basins of the United States hinges on a number of unresolved questions: (1) Volumes of high-enthalpy waters that may be retrieved by wells, (2) average temperature of these waters, and (3) economics. Porosity, permeability, bed thickness, lateral continuity, and other factors determine the amount of water that may be retrieved by wells. These quantities are not well known, especially for the deepest parts of sedimentary basins which may be the most important. The simple projection of near-surface temperature gradients in sedimentary basins, according to Grossling, generally underestimates the temperatures in the deeper parts of the basins where surface gradients are depressed because of subsidence and sedimentation. The economics of the exploitation of the high-enthalpy water would depend on the depth range of the wells, production characteristics of the wells, and the nature of the solids dissolved in the waters.

The sedimentary basins of the conterminous United States have a total area of about 4.9×10^6 km^2, which is about 60 percent of the total area. Moreover, the total sedimentary volume is on the order of 33×10^6 km^3. The maximum depth to basement may be as high as about 18 km. Of the total volume, perhaps about 2.1×10^6 km^3 lies below 4 km depth, and about 30.9×10^6 km^3 lies above it. Assuming that the pore space is filled with water at a mean temperature of $150^\circ C$ ($\approx 300^\circ F$) and that porosity is 5 percent, averaged throughout the total thickness, the total in situ heat of the interstitial water below 4 km is 1.6×10^{22} cal. The considerable magnitude of this total can be appreciated by comparing it with the heat of combustion of 1 million barrels of oil, which is about 1.4×10^{15} cal. That is, the total sensible heat stored in interstitial waters of sedimentary basins of the United States below depths of 4 km may be on the order of the heat of combustion of 10 trillion barrels of oil. The figures for the low-enthalpy waters above 4 km are nearly an order of magnitude greater. The amount of recoverable heat is obtained by multiplying the above in situ figures by a factor which may

range as high as 10^{-2} to 10^{-1}. Thus, the recoverable amounts are still considerable.

A particularly important objective is finding sedimentary basins with large volumes of interstitial waters in their deep parts, which overlie areas with an abnormally high temperature at the mantle-crust boundary. The Gulf Coast geosyncline and the Imperial Valley–Mexicali Valley area are perhaps the two most important exploration targets in the United States in this respect. For instance, for an area of 100×100 km underlain by a layer within the sedimentary column containing permeable beds with an average porosity of 5 percent, a thickness of 1 kilometer, and an average temperature of 250°C, the heat of the water above surface temperature is on the order of 10^{20} cal; this value is equivalent to the heat of combustion of 90 billion barrels of oil. Thus, even if only a small fraction of the water could be retrieved, still the magnitude of the recoverable energy is considerable.

Geothermal reservoirs

L. J. P. Muffler and D. E. White (1972) have published crude estimates of the stored heat in all reservoir types throughout the world. They support White's earlier rough calculation of 3×10^{26} cal in rocks at all temperatures above ambient to a depth of 10 km, which is not incompatible with the estimates of B. F. Grossling described above. White's calculation is based on world-wide average heat flow and thermal conductivities of rocks, which indicate an average temperature gradient of about 20°C/km of depth. Most of this heat is too dispersed to be of economic interest; the calculation is comparable to total aluminum content—or uranium content—of average rocks in the crust of the earth. Such geothermal heat cannot be considered either a resource or reserves recoverable under present technological and economic conditions.

The fraction of total heat in the world's geothermal "hotter spots" (convection systems, deep sedimentary basins, volcanic terrain, and so forth) that should be considered as resources usable and recoverable under any likely conditions is highly speculative and depends mainly on one's assumptions. Muffler and White (1972) suggest that about 10^{23} cal (or 0.03 percent of the total) is likely to be sufficiently hot, recoverable, and near enough to the surface to be considered as a world resource and is approximately equivalent to the heat represented by the world's potential resources of coal. However, if the major emphasis of geothermal energy continues to be restricted to electrical generation by proven techniques (that is, direct input of steam to a turbine), the world's potential geothermal resources to a depth of 10 km are only about 10^{20} cal (recoverable in electrical equivalent). To a depth of 3 km (the deepest well drilled to date for geothermal power), the potential resources for electrical generation by proven techniques are even less (2×10^{19} cal recoverable in electrical equivalent). Use of geothermal resources for other than electrical generation (that is, heating, desalination, horticulture, and so forth) would increase these potential geothermal resource estimates perhaps by 100 times, but all these uses involve special geographic and economic conditions and (or) major technological advancements that have not been achieved to date.

Geothermal resources of Imperial Valley, California

A short-term preliminary appraisal of ground water in storage in the Imperial Valley area of southern California has been completed for the U.S. Bureau of Reclamation by L. C. Dutcher, W. F. Hardt, and W. R. Moyle, Jr. (1972). This report is the first to describe the geothermal system in the Imperial Valley from the field of hydrology and consists of three parts: (1) A summary of theory, (2) a hydrologic evaluation of the system, and (3) a lengthy bibliography.

The Gulf of California, including the Imperial Valley, coincides with the intersection of the East Pacific Rise and the North American Continent. Heat flow through as much as 20,000 ft of water-saturated sediments is greater than the worldwide average, with several small areas as much as 10 times average. Active metamorphism, due to the extremely high temperatures at depths throughout the basin, has caused changes in the original porosity and permeability of the rocks and deposits. The very hot water contains as much as 260,000 mg/l dissolved solids.

The total ground water in the Imperial Valley, recoverable without regard to costs and containing less than 35,000 mg/l dissolved solids, is estimated to be 1.1 billion acre-ft, of which about 200 million acre-ft are probably at a temperature of 150°C or greater. Low well yields and high energy costs may limit usable recoverable water to about 100 million acre-ft. About 62 percent of the recoverable water is derived from the Colorado River, and 38 percent, from local sources.

Large-scale water production and injection may constitute subsidence, seismic noise, air and water pollution hazards. These environmental factors must be carefully evaluated.

EXPLORATION RESEARCH

Aerial geochemical studies

Puerto Rico.—Gold anomalies of high geochemical relief have been found by R. E. Learned (USGS) and Rafael Boissen (Bur. Nat. Resources, Puerto Rico) in the soils overlying known porphyry copper deposits in the Tanama-Helecho district of west-central Puerto Rico (Learned and Boissen, 1972). The finding corroborates their earlier results for the Cala Abajo–Piedra Hueca district, 15 km to the southeast of the Tanama-Helecho district. Additional importance can thus be attached to the use of gold as a pathfinder element for porphyry copper exploration in Puerto Rico and similar environments elsewhere. Copper and other acid-leachable elements are less reliable indicators than gold for exploration purposes because their content in soils over copper deposits is

strongly affected by the leaching processes related to secondary enrichment.

Eureka district and vicinity, Nevada.—Geochemical data from soil samples collected by M. A. Chaffee in the Eureka mining district, Nevada, and to the south and east of the district indicate that some areas contain anomalies for up to 15 elements, including base, precious, and other metals. Anomalous areas are mainly confined to specific carbonate formations (Hamburg Dolomite, Eldorado Dolomite, Geddes Limestone, Hanson Creek Formation, Pogonip Group, and Devils Gate Limestone) within certain antiformal structures.

Central Maine.—Geochemical data on approximately 6,000 stream sediment samples collected in central Maine have been evaluated statistically and contour plotted using computer techniques. According to M. A. Chaffee, J. M. Botbol, and J. C. Hamilton, the contour maps reveal high concentrations of many elements locally as well as regionally. Some of these highs can be related to known mineral concentrations; however, the causes of many of the highs are not known. Some of the areas of high metal concentration may represent potential mineral exploration targets.

Southwest New Mexico.—Structurally controlled base- and precious-metal anomalies were delineated in southwest New Mexico in the southern San Mateo Mountains, in the Sierra Cuchillo, and in the eastern margin of the Black Range by H. V. Alminas and K. C. Watts, Jr., using semiquantitative spectrographic analyses of stream sediment concentrates. In the southern San Mateo Mountains, a 40-sq-mi area, tentatively identified as a caldera, contains anomalous amounts of Pb, Zn, Sb, Au, Ag, Sn, Be, Nb, and La. Anomalies in the Sierra Cuchillo and in the eastern margin of the Black Range are similar. Parallel Pb, Zn, Ag, Sn, W, and Mo anomaly belts with a northwest trend may converge in the vicinity of Hillsboro-Kingston. The anomalous values in the Sierra Cuchillo appear to correlate with cross fractures resulting from igneous doming and (or) Basin-Range faulting.

Clear Creek County, Colo. The distribution of anomalous amounts of Au, Ag, Cu, Pb, Zn, Cd, Mo, Bi, and Sn in the ash of mull collected by G. C. Curtin and H. D. King in a 6-sq-mi area south of Idaho Springs, Clear Creek County, Colo., roughly correlates with a large gravity low. Although the gravity low does not coincide with any known large Tertiary intrusive bodies, similar gravity lows in the nearby mineral belt do coincide with large bodies of Tertiary intrusive rocks and associated mineral deposits. The geochemical anomalies in the ash of the mull may reflect leakage from a buried intrusive body, suggested by the presence of the gravity low, and possibly mineralized rock at depth.

New exploration techniques

Volatile exudates from coniferous trees. Preliminary studies by G. C. Curtin and H. D. King suggest that metals and other elements may be transpired into the atmosphere by coniferous vegetation as constituents of volatile exudates. The volatile exudates were obtained by enclosing branches of conifers in polyethylene bags. The ash of exudates obtained in this manner from 11 localities in mineralized areas in Colorado and Idaho contained Sb, As, Ba, Be, Bi, B, Cd, Cr, Co, Cu, Ga, Fe, La, Pb, Mg, Mn, Mo, Ni, Ag, Na, Sr, Sn, V, Y, Zn, Zr. The presence of these elements in the exudates suggests the possibility that air sampling and analysis of aerosols derived from volatile exudates may be a useful means of geochemical exploration in forested regions.

Trace elements in jasperoid.—T. G. Lovering found that spectrographic analyses of tungsten-bearing samples, collected by A. V. Heyl, of ferruginous jasperoids, gossans, and fracture zones from lower Paleozoic sedimentary rocks near Pando, Eagle County, Colo., show anomalously high concentrations of beryllium, germanium, rare earths, and arsenic in addition to tungsten. The presence of these elements in samples from gossans and fracture zones below the jasperoid suggests that they were deposited by upward-moving hydrothermal fluids emanating from a shallow igneous intrusive source.

Fluid inclusions.—Petrographic studies by J. T. Nash of hydrothermal alteration and fluid inclusions in many western ore deposits reveal several associations which may find application to exploration for ore deposits. One association is high salinity, halite-bearing fluid inclusions in 28 of 30 porphyry-type deposits studied. In contrast to disseminated copper and molybdenum mineralization, lead, zinc, gold, and silver are generally deposited from relatively low salinity fluids represented by simple fluid inclusions of liquid and vapor. Alteration and metallization zones commonly correspond to zones having fluid inclusions of different composition. Likewise, lateral and vertical changes in fluid inclusions may foretell favorable or unfavorable ore zones. At the Jamestown, Colo., district, which is a major source of fluorite and formerly was a gold and gold telluride district, fluid inclusions from fluorite deposits differ chemically and physically from those in gold veins. The fluorite-depositing fluids were very saline (26–40 percent) and hot (300–350°C), whereas the gold-depositing fluids were cooler and much less saline.

Utilization of trace elements in minerals for exploration

Trace constituents of several minerals may be useful in ore exploration. USGS geochemists have become particularly interested in the trace-element content of magnetite and gold. Both minerals are readily obtained from many environments, and trace-element analyses made on them may reveal interesting prospecting applications.

Radioactive detrital magnetite.—W. C. Overstreet reported that 1-g magnetic fractions of 348 panned concentrates from the Alaskan concentrate file were examined for equivalent uranium by Kuo-Liang Pan (Inst. Nuclear Energy Research, Taiwan, Republic of China) using an end-window Geiger-Muller tube housed in a 4-cm-thick lead shield. The lower limit of detection was determined to be 0.003 percent eU, and 123 of the 348 samples had eU values greater than that. The source

of the radioactivity in the mineral grain has not been identified. Most (118) of these radioactive magnetic fractions are from concentrates in the Candle, Bendeleben, Solomon, and Norton Bay quadrangles in the Seward Peninsula. Geologic mapping in these quadrangles by USGS personnel shows that the drainage basins of the streams from which the radioactive magnetic fractions came are underlain by alkalic igneous rocks. If magnetic fractions of concentrates from stream sediment in other areas of alkalic intrusive rocks also are found to be radioactive, then a new method for use in locating such rocks in heavily forested and deeply weathered areas has been developed for reconnaissance geologic surveys.

Trace elements in gold.—J. C. Antweiler and W. L. Campbell have found that alloy proportions of gold, silver, and copper in native gold together with certain trace elements constitute a gold "signature" by which gold from a particular deposit can be recognized. For example, gold from the Hahns Peak area, Routt County, Colo., has a high silver content (30–40 percent), a low copper content (less than 25 ppm) and minimal amounts of all trace elements except lead. In contrast, gold from the Atlantic City district, Fremont County, Wyo., has a relatively low silver content (5–10 percent), a high copper content (500–2,000 ppm) and several diagnostic trace elements (As, Sb, B, Co, Ni, Pb, Sn, V, and W). Some elements identified in gold (for example, tin and tungsten in the Atlantic City district; tin in the Virginia City district, Montana; platinum in the Seafoam mine, Custer County, Idaho; and molybdenum at Gold Basin–Lost Basin, Mohave County, Ariz.) suggest that the area from which they came may be worthy of exploration for those elements in addition to gold.

Statistics applied to geochemical prospecting

G. B. Gott, J. H. McCarthy, Jr., and J. M. Botbol, using computer-generated stereopairs of metal ratios, determined the zoning order of most of the sulfide-forming metals in the Robinson mining district near Ely, Nev. Two hundred fifty stereopairs, showing all possible ratio combinations among the sulfide-forming metals, were examined with a mirror stereoscope. This examination of the ratio maps resulted in the establishment of a zoning order among the sulfide-forming metals. Going outward from the center of the district, the zoning order of the chalcophile elements is as follows: Cu, Fe, Zn, Cd, Te, Sb, As, Pb, Hg, and Ag. The following table compares the zoning order with the ionic radii:

Zoning order of some chalcophile elements	*Ionic radii*	
	Ahrens (1952)	*Goldschmidt (1958)*
S	....	1.74
Cu	0.72	....
Fe	.74	....
Zn	.74	....
Cd	.97	....
Te	....	2.11
Sb	....	2.1
As	....	2.22
Pb	1.20	....
Hg	1.10	....
Ag	1.26	....

The ionic radii of molybdenum and bismuth, which come in the zoning order between iron and zinc, do not fit in the above arrangement.

Geochemical sample-index numbers

Sample-index numbers, generated by summing weighted individual amounts of selected elements found during reconnaissance geochemical surveys, have been used by Helmuth Wedow, Jr., to reduce the number of maps needed to show areas of complex mineralization. Scarcer elements that occur in widely disparate amounts in a sample are combined into one number for that sample. Normally, an element is weighted according to its degree of dispersion above a critical base point in its frequency distribution; however, various other weighting methods may be used, depending on the desirability of strengthening the influence of one or more elements over the others of a particular suite. This index-number technique has been found useful thus far not only with the more complex suites (for example, Ag-Au-Cu-Mo-Pb-Zn and Ag-As-Au-B-Cu-Mo-Pb-Zn) as obtained with data from some of the western wilderness resource surveys but also with the relatively more simple Zn-Pb-Cu suite of elements sought in geochemical studies conducted in the east Tennessee zinc districts.

Instrumental techniques

C. G. Bowles and F. A. Swenson report that a combined Eh, pH, and sulfide-ion-activity logging system, which is in the testing stage of development, has considerable potential for application to the exploration for uranium deposits located at oxidation-reduction barriers in sedimentary rocks. The system was logged successfully in borehole fluids to depths of nearly 1,000 ft in the Black Hills. Calibration on the Eh and pH logs permits quantitative use of the data.

Borehole probe for mineral exploration

F. E. Senftle, R. M. Moxham, and A. B. Tanner have constructed a probe for borehole logging of 30 or more elements by measuring delayed gamma ray spectra produced by in situ neutron activation. Previous attempts at borehole logging have been limited by the size of equipment that can be lowered into boreholes and by the use of detectors that operate at ordinary temperatures. Size limitations were overcome by using a californium-252 neutron source. Much higher resolution of gamma-ray spectra than can be obtained through conventional scintillation detectors was achieved by using the most modern gamma-ray detector—a lithium-drifted germanium crystal. Use of this detector was formerly precluded because it must be operated at very low temperatures which were usually obtained with liquid nitrogen. Problems of handling liquid nitrogen were overcome by substituting solid propane as the cryogen.

New analytical techniques

Selective dissolution of manganese oxides.—Hydrous manganese and iron oxides are strong scavenging agents for heavy-metal ions. A method to differentiate between metal ions associated with manganese oxides and those associated with iron oxides was developed by T. T. Chao whereby manganese oxides are preferentially dissolved, leaving the major part of iron oxides in the residue. The procedure consists of equilibrating soil or sediment samples for 30 min with a 0.1 *M* hydroxylamine hydrochloride solution prepared in 0.01 *M* HNO_3 (pH 2) and determining manganese, iron, and other metal ions in solution. On the average, 85 percent of the total manganese and about 5 percent of the total iron are dissolved from various sediment samples by this method. Iron oxides and associated metals left in the residue may then be determined separately. The method is expected to have use in determining enrichment of trace metals in manganese oxide minerals and deep-sea ferromanganese nodules or concretions.

Atomic-absorption determination of thallium and indium.—An atomic-absorption method was developed by A. E. Hubert and H. W. Lakin (1972) for the determination of thallium and indium in geologic materials. Fifty samples can be analyzed per man-day for the two elements, with a detection limit of 0.2 ppm for each element. The relative standard deviation ranges from 4.6 to 8.8 percent for thallium and from 2.4 to 9.2 percent for indium.

Catalytic determination of tellurium.—A sensitive method for the determination of tellurium in geologic materials useful in geochemical exploration studies was described by A. E. Hubert (1971). The method involves catalytic estimation of tellurium with a lower sensitivity limit of 5 ppb. The relative standard deviation ranges from 0 to 43 percent.

Emission spectrographic analysis of plant ash.—A visual comparison method for semiquantitative spectrographic analysis of plant ash by d-c arc technique was developed by E. L. Mosier. A split-slit technique utilizing a Hartmann diaphragm and step-filter assemblage enables the simultaneous recording of volatile elements (As, Bi, Ag, Zn, and so forth) from a short burn at 100 percent transmission and less volatile elements from a total energy burn at 15 percent transmission, all from the same electrode charge. Standards in a plant-ash base are prepared in progressively lower concentrations from spectrographically pure powders in ranges applicable to most plants. Repeatability is within one reporting interval of the standards at the 68-percent confidence level and within two reporting intervals of the standards at the 95-percent confidence level.

MINERAL INVESTIGATIONS RELATED TO THE WILDERNESS ACT

The Wilderness Act of 1964 directs the Secretary of Agriculture and the Secretary of the Interior to review the suitability or nonsuitability of lands being considered for inclusion in the National Wilderness Preservation System. As one aspect of the reviews, the U.S. Geological Survey and the U.S. Bureau of Mines are making mineral surveys of primitive and other areas of the national forests that are being considered for wilderness inclusion. Mineral surveys of wilderness areas that were established by the Wilderness Act are also under way.

PRIMITIVE AREAS

Mineral surveys have been completed and the reports published as Geological Survey bulletins on 27 of the 34 primitive areas that are identified with the Wilderness Act. The reports on the remaining seven areas are in various stages of preparation, but they will be available by 1973. In fiscal year 1972, reports were published for the following primitive areas.

Wilson Mountains Primitive Area, Colorado

The main geologic features of the Wilson Mountains Primitive Area were caused by middle Tertiary intrusion of an east-west belt of composite stocks, laccoliths, sills, and dikes into nearly flat-lying Mesozoic sedimentary and overlying Tertiary sedimentary and volcanic rocks. Narrow base- and precious-metal fissure veins cut intrusive rocks and adjacent sedimentary rocks.

The mineral survey of the Wilson Mountains Primitive Area, southwestern Colorado, by C. S. Bromfield (USGS) and F. E. Williams (USBM) covered an area of about 68 sq mi. Mines in the area and in the western San Juan Mountains have yielded gold, silver, lead, copper, and zinc valued at 1.78 million dollars. About 96 percent of this total is from two mines, the Silver Pick mine in the Mount Wilson district and the San Bernardo mine in the Trout Lake district.

The Mount Wilson mining district in the center of the primitive area contains an area of disseminated copper mineralization in the quartz monzonite of the Wilson Peak stock and several narrow base- and precious-metal veins, one of which had a moderate gold production late in the last century. (See Bromfield and Williams, 1972.)

Popo Agie Primitive Area, Wyoming

The Popo Agie Primitive Area encompasses about 100 sq mi of the southeast flank of the Wind River Range and adjoins the east boundary of the Bridger Wilderness. Two large plutons—quartz diorite of the Louis Lake batholith and porphyritic quartz monzonite of the younger Popo Agie batholith—occupy nearly the entire area. Only two small remnants of pre-batholithic gneiss remain. Dikes of diabase and feldspathic peridotite are the youngest rocks in the area. All bedrock in the area is Precambrian in age.

No mineral concentrations of economic value or evidence of former mining activity were found within the primitive area studied by R. C. Pearson and T. H. Kiilsgaard (USGS) and

L. L. Patten (USBM). Analysis of more than 500 samples of stream sediment, pan concentrates of stream gravels, and rock did not indicate the presence of commercial deposits of ore minerals or of potential mineral deposits. Likewise, the aeromagnetic data compiled and interpreted by R. E. Mattick (USGS) did not reveal any evidence of potentially iron mineralized areas. (See Pearson, Kiilsgaard, and Patten, 1971.)

WILDERNESS AREA

A report was published for the following wilderness area during fiscal year 1972.

Pasayten Wilderness Area, Washington

The mineral survey covered about 900 sq mi in northern Washington which included the Pasayten Wilderness, eastern part of the Ross Lake National Recreation Area, and certain adjacent lands south and east of the wilderness area.

Geologically, the area is divided into two contrasting parts by the northwesterly trending Eight Mile Creek fault, a major structure that crosses the entire width of the wilderness area. The area east of the fault is underlain by igneous and metamorphic rocks that contain few mineral showings. West of the fault a broad medial belt of arkose and argillite is underlain and overlain on the east by volcanic rocks and faulted on the west against greenstone and chert. In the southwest there is a small area of hornblende and biotite gneiss. Numerous bodies of diverse intrusive rock are west of the fault, and mineral showings are relatively abundant.

The mineral surveys by M. H. Staatz, P. L. Weis, R. W. Tabor, and J. F. Robertson of the U.S. Geological Survey and R. M. Van Noy, E. C. Pattee, and D. C. Holt of the U.S. Bureau of Mines list 605 lode and placer claims in the area (Staatz and others, 1971). Although mineralized rock is present in many places, only four areas appear to have a mineral potential. Numerous geochemical anomalies of copper and molybdenum are in and around the Monument Peak granite stock which is in the south-central part of the area. Veins at the southeast edge of the area contain fairly abundant copper and silver minerals. The veins with the greatest potential lie within a half a mile of the wilderness area boundary. Small discontinuous quartz veins with erratic gold values are in a band about 1 to 2½ mi wide along the south boundary of the area. The Tungsten Creek basin, near the Canadian border in the eastern part of the study area, contains tungsten-bearing quartz veins. Attempts to mine these veins in the past apparently proved uneconomic.

OFFICE OF MINERALS EXPLORATION

Financial assistance to explore deposits of eligible minerals is offered on a participating basis to private industry by the USGS Office of Minerals Exploration (OME) under Public Law 85-701. Assistance is available to those who would not ordinarily undertake the proposed exploration at their sole expense and who are unable to obtain the necessary finances on reasonable terms from commercial sources. Prospecting ventures or projects to develop properties for mining are not eligible for assistance.

An applicant must have rights to possession of a specific property he wishes to explore for a period of time at least sufficient to complete the exploration. A reasonable geologic probability must exist for a significant discovery of ore being made on the property by the exploration specified in a contract. Repayment of Federal funds expended on a contract plus simple interest is made through a 5 percent royalty on mineral production from the property. If the Government issues a certification of possible production, the royalty period continues for not less than ten years, or until the principal and interest are repaid in full, whichever occurs first. In the event that there is no production, no repayment is required. The Government is not obligated to purchase any production.

The following 27 minerals or mineral products are eligible for Government financial assistance of 50 percent of the allowable costs of exploration:

Asbestos	Kyanite (strategic)
Bauxite	Manganese
Beryllium	Mica (strategic)
Cadmium	Molybdenum
Chromite	Monazite
Cobalt	Nickel
Columbium	Quartz crystal (piezoelectric)
Copper	Rare earths
Corundum	Selenium
Diamond (industrial)	Sulfur
Fluorspar	Talc (block steatite)
Graphite (crucible flake)	Tellurium
	Thorium
Iron ore	Uranium

The following 9 minerals or metals are eligible for Government financial assistance of 75 percent of the allowable costs of exploration:

Antimony	Rutile
Bismuth	Silver
Gold	Tantalum
Mercury	Tin
Platinum-group metals	

Combinations of the minerals or mineral products listed in the 50- and 75-percent assistance groups may be eligible for Government financial assistance of 62.5 percent of the allowable costs of exploration.

Activity on the OME program in calendar year 1971 and totals for the program through December 31, 1971, were as follows on page A16.

	Calendar year 1971	Program totals 1958 through 1971
Applications		
Received	31	[1]897
Denied	14	373
Withdrawn	17	315
Processing completed	41	866
Total in process Dec. 31, 1971	13	.....
Contracts		
Executed	10	196
Total value	$491,650	$12,508,870
Government share	314,353	7,182,589
Government share spent	[2]211,655	4,357,419
Repaid to Government through royalties on production	3,620	389,803
Estimated recoverable value of reserves in year discovered	5.2 million	95 million

[1] Total estimated cost of proposed exploration $86.6 million.
[2] Disbursements on all active contracts during the year.

Projects to explore for silver and gold accounted for about 65 percent of the total value of contracts conducted on the program from 1958 through 1971 as shown:

Commodity	Number of contracts	Total value of contracts	Percentage of total value
Silver	70	$5,296,000	42
Gold	57	2,857,000	23
Mercury	17	1,162,000	9
Copper	14	858,000	7
Lead-zinc	7	682,000	5
Lead-zinc-copper	11	488,000	4
Molybdenum	3	384,000	3
Iron	3	200,000	2
Beryllium	3	127,000	1
All others (cobalt, fluorspar, mica, nickel, platinum, uranium)	11	455,000	4
Total (15 commodities)	196	12,509,000	100

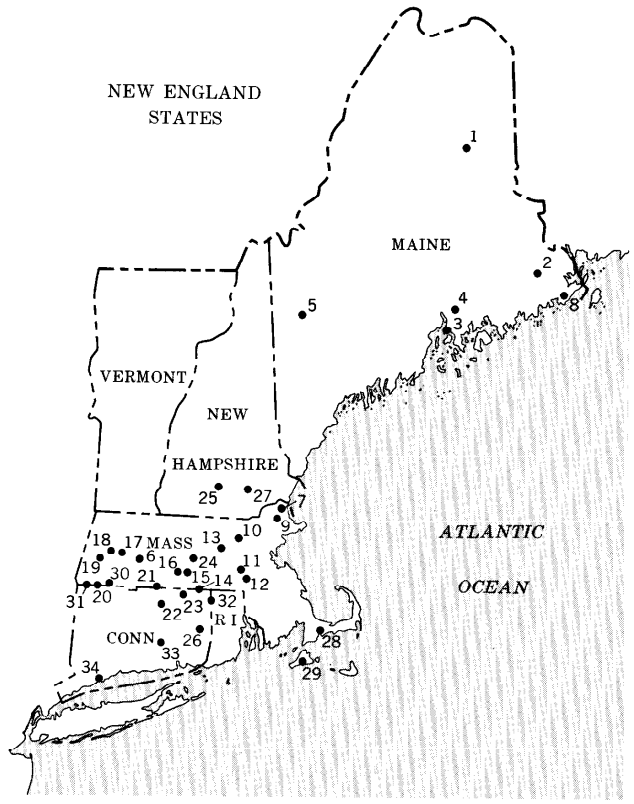
GEOLOGICAL, GEOPHYSICAL, AND MINERAL-RESOURCE STUDIES

NEW ENGLAND

ADVANCES IN GEOPHYSICAL TECHNIQUES

Use of airborne VLF method in geologic mapping

A preliminary comparison of airborne VLF radio-wave data with ground electromagnetic (Slingram) data by F. C. Frischknecht in the Island Falls, Shin Pond, and Smyrna Mills quadrangles, Maine (loc. 1, index map) indicates that the VLF technique is an effective means of mapping conductive slates. In addition to sharp anomalies from known conductors, broad anomalies having wave lengths as much as a few miles were mapped. These broad anomalies may represent small conductivity contrasts between large geologic units.



STRUCTURAL AND STRATIGRAPHIC STUDIES

Extension of the New Brunswick tin "belt" into southeastern Maine

Geologic and geochemical reconnaissance by R. H. Moench in southeastern Maine (loc. 2) suggests that the tin "belt" of southern New Brunswick (J. E. Riddell, 1962; A. A. Ruitenberg, 1968) extends to the southwest into Maine along the northwest side of the coastal mineral belt. Crystals of cassiterite were found at the Wesley (Rollins) prospect near Wesley village in south-central Washington County. The cassiterite is associated with arsenopyrite in quartz veins; wallrocks (dark Ordovician phyllite) are impregnated with tourmaline. Tin was detected in two bulk sediment samples (30, 50 ppm) from streams on the trend of the tin "belt," in three specimens of the Red Beach Granite of Amos (1958) (10–15 ppm), and in many panned concentrates of heavy minerals from the project area. Most panned concentrates with

detectable tin (10–300 ppm) were obtained from stream and beach sands in areas underlain by the Perry Formation (Upper Devonian). The Perry was deposited by vigorous southeast-flowing streams and contains abundant clastic material derived from the general area of the projected tin "belt." Gold, chromium, and lead also were detected preferentially in concentrates obtained from the area of the Perry Formation.

Geochronological studies in Penobscot Bay, Maine

D. B. Stewart and J. M. Berdan, in collaboration with D. G. Brookins (Univ. New Mexico), report that isotopic and paleontologic studies have shown the correlation of the Castine Volcanics, the Thorofare Andesite-Vinalhaven Rhyolite sequence, and the Cranberry Island Series of Shaler (1889) with each other in the Blue Hill and Castine quadrangles, Maine (loc. 3). These volcanic formations, although partly Late Silurian (Pridoli), are mostly Early Devonian (Gedinnian) in age (390±5 m.y.).

Lucerne pluton, Orland, Maine

Field investigations of D. R. Wones have shown that the Lucerne pluton near Orland, Maine (loc. 4) is a coarse-grained intrusive body of quartz monzonite with an average grain size of 1–2 cm. Although its western contact is unusually straight, the contact is intrusive, not faulted. Foliations are common on the western margin and trend N. 25° E., parallel to cleavage in the host rocks. The pluton is devoid of pegmatites and miarolitic cavities. Aplite dikes are rare. Biotite is a minor constituent and magnetite is virtually absent. The body is interpreted to have crystallized at depths greater than 3 km from magma undersaturated with respect to water. There are no metal deposits associated with the pluton in Hancock County, and the rocks have only been quarried for foundation stone.

Paleotectonics and metallic mineral deposits, northern Appalachians

Review of geologic literature on the northern Appalachians suggests to R. H. Moench that the active or potential metal-producing areas are closely related to major tectonic and paleotectonic features. These are the (1) Kennebecasis anticlinorium along the coast of southern New Brunswick and southeastern Maine, (2) Miramichi anticlinorium of New Brunswick, (3) Bronson Hill–Boundary Mountain anticlinorium of New Hampshire and northwestern Maine, (4) Green Mountain–Sutton Mountain anticlinorium of Vermont and Quebec, and (5) Shickshock region of the Gaspé Peninsula. All these features approximately coincide with geanticlines of long ancestry.

Factors that apparently contributed to mineralization of the coastal mineral belt along the Maine extension of the Kennebecasis anticlinorium are the (1) persistence of the area in early and middle Paleozoic time as a submarine, and at times terrestrial, volcanic tract that was bordered by largely nonvolcanic deeper marine sedimentary troughs, (2) presence of granitic plutons with epizonal characteristics along the tract in contrast with mesozonal plutons elsewhere, and (3) long structural, volcanic, and plutonic history providing multiple opportunities for deposition and redeposition of metallic mineral deposits.

The tract of no Taconic unconformity defined by Louis Pavlides and others (1968) effectively separates the mineralized anticlinoria of New Brunswick and southeastern Maine from those of northern New Hampshire, northwestern Maine, and Quebec. This tract is the axial region of a broader, largely nonvolcanic sedimentary trough that persisted at least from Middle Ordovician through Early Devonian time. Mapping in western Maine by R. H. Moench and C. T. Hildreth suggests that the trough was also the locus of large-scale slump faulting and folding. It forms a slight low in the regional gravity field. Except for a few small deposits that may be associated with the Devonian plutonic belt (which crosses the trough), the trough is considered to be unfavorable for metallic mineral deposits.

Devonian mafic-ultramafic rocks in western Maine

Premetamorphic faults in the northwest limb of the Merrimack synclinorium of western Maine controlled the emplacement of mafic-ultramafic intrusive rocks. Recent mapping by R. H. Moench and C. T. Hildreth in the Rumford quadrangle (loc. 5) shows that the mafic intrusions are sheetlike bodies mostly emplaced along the Blueberry Mountain and Plumbago Mountain faults. The primary mineralogy of the mafic-ultramafic rocks is not preserved because of intense deformation and recrystallization. Two principal rock types are recognized: (1) Iron-rich biotite-hornblende metagabbro and metadiorite and (2) magnesian(?) tremolitic metagabbro and metadiorite, commonly with white magnesium chlorite. Both rock types may occur in the same intrusive bodies, but their relations are obscure. Forsterite-bearing serpentinite was found in one outcrop in a large body of the magnesian(?) metagabbro along the Plumbago Mountain fault. The mafic-ultramafic rocks intrude Silurian and Devonian metasedimentary rocks and are the oldest of the following intrusive sequence: (1) Mafic-ultramafic rocks, (2) biotite-rich quartz diorite, (3) trondjemite, granodiorite, and quartz monzonite, and (4) alaskitic rocks and pegmatites. Quartz monzonite and related rocks have yielded a radiometric age of about 380 m.y. (Rb/Sr, whole rock; by R. E. Zartman). The entire plutonic sequence of intrusions together with associated deformation and metamorphism apparently was compressed into a brief time interval early in the Devonian.

Silurian and Devonian rocks in western Maine

Mapping by R. H. Moench and C. T. Hildreth in the Rumford quadrangle, western Maine (loc. 5), has helped to

substantiate a correlation of Silurian and Devonian rocks across the Merrimack synclinorium. Ordovician, Silurian, and Lower Devonian formations on the northwest limb of the synclinorium (Moench, 1971) have been difficult to correlate with units on the southeast limb (P. H. Osberg and others, 1968) because recognized rock types were not closely similar and because the Blueberry Mountain fault (Moench, 1970), a major premetamorphic fault, was present.

Rocks equivalent to the Silurian(?) Perry Mountain, Smalls Falls, and Madrid Formations of the northwest limb have now been recognized in places in the southeast limb, and stratigraphic correlation across the synclinorium has thus been established. The equivalent rocks on the southeast limb are overlain by a thick mass of dominantly pelitic rocks, including the Hildreths Formation, a thin but extensive unit of arenaceous and calcareous rocks. The pelitic rocks and Hildreths Formation are inferred to be partly equivalent to and partly younger than the Seboomook(?) Formation (Lower Devonian) which overlies the Silurian(?) rocks on the northwest side of the synclinorium. The Merrimack synclinorium in western Maine is now reaffirmed as a major structural feature with probable Devonian strata along much of its axis and Silurian and older strata along its limbs.

Asphalt stripping on highways

Crushed basaltic "traprock" is commonly used for aggregate in bituminous concrete (asphalt) highways in New England because this aggregate provides a tough, rough-toothed surface. Chlorite, however, may be abundant enough to produce "pop-outs" or stripping of individual pebble-size aggregate fragments. Because of its greasy surface and its thin, platy habit, chlorite effectively promotes stripping. The major effects of stripping are (1) open holes in the pavement surface that become larger during the freeze-thaw season, and (2) reduced friction which increases the probability of skidding. Two trap agregates, the Holyoke Basalt and the Deerfield Diabase, were studied by C. R. Tuttle and Fred Pessl, Jr., at two quarry sites in the Connecticut Valley (loc. 6). These rocks contained less than 2 percent chlorite, but the crushed rock was heavily coated with rock dust which was difficult to remove by soaking and brushing and would have the same effect as chlorite. Treatment at the plant, therefore, may be as important a factor as deleterious mineral content in producing high-quality bituminous concrete aggregate.

Different volcanic centers in Massachusetts and Maine

The Newbury Formation of northeastern Massachusetts (loc.7) and some other volcanic sequences along the coast of Maine have long been known from paleontologic studies to be at least in part comparable in age (Late(?) Silurian–Early(?) Devonian). Recent comparisons of the Newbury and the volcanic complex of the Machias-Eastport region of northeastern Maine (loc. 8) by A. F. Shride indicate that the two complexes are petrographically and stratigraphically quite different and probably evolved from different centers of volcanic activity. D. B. Stewart, on reviewing the Newbury sequence, however, suggests that it does have much in common with the Castine Volcanics and associated volcanics of the Penobscot Bay area of south-central Maine (loc. 3).

Post-Paleozoic volcanics in northeastern Massachusetts

Volcanic rocks that have no appreciable resemblance to any other volcanic rocks of the region have been found by K. G. Bell in the Georgetown and South Groveland quadrangles of Massachusetts (loc. 9). These rocks are porphyritic biotite-rich andesites and dacites that generally have well-developed flow features. They are unmetamorphosed and do not show the cataclasis that is a common feature of other rocks of the region. The appearance of these volcanic rocks is generally similar to that of some volcanics of Tertiary age in the western United States. They rest unconformably upon diorite and gneiss considered to be of Early Paleozoic age. These volcanic rocks may be remnants of a previously unknown post-Paleozoic volcanic unit.

Structure and stratigraphy of eastern Massachusetts

In the Westford quadrangle, Massachusetts (loc. 10) about 25,000 ft of metamorphosed strata that form the upper half of the Nashoba Formation have been subdivided into eight map units by D. C. Alvord. This part of the Nashoba is between the "Fox Hill Member" of the Nashoba on the south and the Brimfield Schist on the north. The new subdivisions are based largely on large-scale lithologic and structural features. Fault contacts are inferred between some of the units; there is folding within the sequence, but repetition of map units within the sequence was not observed. This work, together with previous work that defined map units within the lower half of the Nashoba in the Billerica and Concord quadrangles, establishes a basis for a tentative elevation of the Nashoba Formation to group status.

In an area of relatively thick glacial deposits, A. E. Nelson used aeromagnetic maps and a distinctive, but as yet unnamed, sequence of quartzite, siliceous ash flows, and mafic tuffs and lava flows to map a complexly faulted area across the northern part of the Framingham quadrangle, Massachusetts (loc. 11). This sequence of units will undoubtedly be useful in working out the complex stratigraphic and structural relationships in adjoining quadrangles and elsewhere in eastern Massachusetts.

Faulting in eastern Massachusetts

Using field data in conjunction with aeromagnetic data, R. P. Volckmann has delineated several significant faults across the Medfield and Holliston quadrangles, eastern Massachusetts (loc. 12). The most persistent fault trends about N. 30° E. through both quadrangles, whereas most other northeast-

trending faults are about N. 70° E. and terminate against the major fault. The northeast-trending faults appear to have right lateral displacement and are up to the northwest. They are connected by a series of north- or northwest-trending cross faults. In the southeast part of the Medfield quadrangle another fault nearly parallel with the main northeast-trending fault separates Norfolk basin sandstones and conglomerates from the Dedham Grandiorite.

"Bouma Beds" in central Massachusetts

Well-preserved graded beds in chlorite- to andalusite-grade metasedimentary rocks have been mapped by J. H. Peck in the Clinton quadrangle, Massachusetts (loc. 13). Many of the graded beds are incomplete or partial "Bouma Beds" (A. H. Bouma, 1962) and fit very closely R. G. Walker's (1967) definition of distal turbidites. Cross laminations present in the "C" or middle subdivision of the "Bouma Beds" indicate that the turbidity currents flowed from west to east. Lobate metasiltstone bodies intercalated in the graded bed sequence are thought to be submarine slump structures and also to indicate a western sediment source. These rocks are part of a thick Silurian to Devonian sequence (Peck, 1971) which forms the east limb of the Merrimack synclinorium in central Massachusetts. The fact that the sediments apparently filled the basin from the west suggests that the regional structure might more aptly be called the Merrimack geosyncline. The source of sediment for these rocks is not evident west of their present location. Lithologic similarities with rocks in central Maine suggest the possibility that the turbidites were deposited tens of kilometers northeast of the Clinton area and subsequently moved southeastward within a large crustal plate.

Structural junction in southern Massachusetts

Work by P. J. Barosh in the Webster and Oxford quadrangles (loc. 14) in parts of Massachusetts, Connecticut, and Rhode Island confirms that the area straddles one of the major structural junctions in New England and bridges the gap between the stratigraphic columns established in northeastern Massachusetts and northeastern Connecticut. Major faults of east-central Massachusetts and eastern Connecticut converge on the area from the northeast, northwest, southeast, and southwest to form somewhat of an hourglass pattern centered along the mutual boundary of the two quadrangles. The northwest contact of the Nashoba Formation, which could possibly correlate with the Tatnic Hill Formation of Connecticut. is offset 8 km left laterally in a southerly direction across this fault junction. The Clinton-Newbury fault zone, which follows this contact in Massachusetts, is apparently also offset southward and ties into a fault mapped to the south by H. R. Dixon. The Nashoba is thinned by faulting as it approaches the area from the northeast. where it is found to be about 50,000 ft thick by D. C. Alvord, and from the south, until it is represented by only a narrow fault sliver in the midst of the fault junction. The Quinebaug Formation, which is about 7,000 ft thick in eastern Connecticut (Dixon, 1964), is completely cut out for a distance of 5 km across the junction. The aeromagnetic data across this fault complex are in excellent agreement with the observed geology, and the magnetic anomalies closely reflect the structural pattern.

Faults in the Warren quadrangle

At least two transverse faults trending approximately N. 50° E. are marked by narrow cataclastic zones, and they offset two mineralogically distinct gneisses in the Warren quadrangle, Massachusetts (loc. 15) according to J. S. Pomeroy. Both gneisses are massive-appearing and weather to gray. One gneiss, at Chamberlin Mountain, is a fine- to medium-grained quartz-plagioclase-biotite-garnet gneiss without potassium feldspar. The other, at East Hill, is coarser grained quartz-garnet-biotite-sillimanite-potassium feldspar-plagioclase gneiss. The transverse faults appear to be truncated on the west by thrust faults which trend north-northeast.

Paleozoic section in Ludlow area, Massachusetts

Detailed mapping in the Ludlow quadrangle, south-central Massachusetts (loc. 16), by G. W. Leo confirms earlier reconnaissance mapping of the southern part of the quadrangle by J. D. Peper (USGS) and recent work in the northern part by D. J. Hall and Peter Robinson (Univ. Massachusetts). Some significant differences from earlier interpretations, however, have been recognized in the Paleozoic sequence in the southeastern part of the quadrangle, as follows:

1. The westernmost unit of the sequence, heretofore regarded as Partridge Formation (Ordovician), is unlike typical Partridge elsewhere but instead shows considerable resemblance to the Waits River Formation (Silurian and Devonian) northwest of Amherst. In both areas these rocks conformably(?) overlie the Erving Hornblende Schist of uncertain age. If the westernmost unit in the Ludlow quadrangle is Waits River, the structural picture is one of a west-facing homocline rather than a highly asymmetric syncline.
2. The Monson Gneiss, only tentatively identified previously in the Ludlow quadrangle, forms a belt as much as 3,000 ft wide between the Glastonbury Gneiss and Ammonoosuc Volcanics; exposures are poor, however, and the outcrop pattern of the Monson in the southern part of the Ludlow quadrangle and in the adjoining Hampden quadrangle is unknown.
3. A narrow unit of quartz-feldspar-biotite-epidote-garnet gneiss between the Monson Gneiss and Ammonoosuc Volcanics cannot be satisfactorily correlated with either of these two units and is provisionally regarded as a separate unit.

Geologic history of part of western Massachusetts

On the basis of a systematic restudy of selected thin sections and previously analyzed field data from the Heath, Plainfield, Worthington, Chester, and Blandford quadrangles (loc. 17) on the east limb of the Berkshire anticlinorium in Massachusetts, N. L. Hatch, Jr., has evolved the following geologic history of the area:

Deposition of sediments occurred during Cambrian and Ordovician time. Volcanic flows and volcanic detritus deposited unconformably on a Precambrian basement were followed by folding (stage 1) accompanying the Taconic orogeny. After deposition of Silurian and Lower Devonian sediments, the Acadian orogeny began. North-trending folding (stage 2) was accompanied by metamorphic recrystallization at biotite grade of muscovite- chlorite- and biotite-forming axial-plane schistosity. Local intrusion of porphyritic quartz monzonite accompanied stage 2 folding. Regional metamorphism reached garnet grade after stage 2. Northeast-trending folding (stage 3) with accompanying axial-plane slip cleavage was accompanied by rise of the Shelburne Falls and Goshen domes. Regional metamorphism reached staurolite grade in the central part and kyanite grade in the south part of the area immediately after stage 3 folding which was accompanied in the kyanite zone by widespread intrusion of sills and dikes of two-mica granite and pegmatite of the New Hampshire Plutonic Series. Folding (stage 4), probably still part of the Acadian orogeny, followed and is the last recognized regionally significant Paleozoic event.

Berkshire massif allochthonous(?)

The Middlefield thrust zone (S. A. Norton, 1971) in western Massachusetts (loc. 18) is from ½ to 6 km wide and has been traced along the entire length of the east side of the Berkshire massif according to S. A. Norton. The zone consists of imbricate layers of Precambrian gneisses and rocks of the Hoosac Formation (Lower Cambrian or older). Zones of cataclasis are as much as 100 m thick. Deformation of Precambrian rocks between individual faults is slight with open folds and no accompanying foliation. The faults were formed prior to stage 3 folds and may predate stage 2 folds, both stages of Acadian age (Norton, 1972). The faults postdate the Walloomsac Formation of Middle Ordovician age (E-an Zen and J. H. Hartshorn, 1966). The Middlefield thrust zone may dip beneath the central part of the Precambrian massif and emerge as steeply east-dipping faults on the west side of the massif. All or most of the Berkshire massif therefore, may be allochthonous.

Layered magnetite, western Massachusetts

A curvilinear magnetic anomaly on the aeromagnetic map of the East Lee quadrangle, Berkshire County, Mass. (loc. 19), extends northwestward from the southeast corner to the west-central part of the map. Detailed mapping by N. M. Ratcliffe has established that this anomaly is associated with a zone of layered magnetite and alaskite that is confined to a major northeast-dipping thrust fault just north of the Massachusetts Turnpike. Nearly pure magnetite (low TiO_2) is found in layers and veinlets 1 to 10 in. in thickness in a matrix of alaskite. The mineralized zone is approximately 100 to 150 ft thick, but the actual beds of pure magnetite represent only a small fraction (10–15 percent) of the total thickness and appear to be developed as podiform deposits lensing out along the strike. No estimates of the downdip extent are possible without further study.

Taconic thrusting along western front of Berkshire massif

Mapping along the western front of the Berkshire Highlands in western Massachusetts and Connecticut (loc. 20) by D. S. Harwood and N. M. Ratcliffe has shown that Precambrian and lower Paleozoic rocks have been transposed southwestward over lower Paleozoic quartzite and carbonate miogeosynclinal rocks along a series of imbricate thrust slices. The youngest miogeosynclinal rocks structurally beneath the Precambrian are assigned to the Walloomsac Formation (Middle Ordovician). The regional metamorphic isograds, assumed to be related to the Acadian orogeny, are not offset by the thrusts; therefore, the thrusting must have occurred between Middle Ordovician and late Early Devonian time. Preliminary U-Th-Pb isotopic work by R. E. Zartman on zircon from a small granite body that cuts one of the thrust faults indicates a Late Ordovician age and, thus, tentatively limits the thrusting to the Taconic orogeny.

Triassic border fault zone, Hampden quadrangle, Massachusetts and Connecticut

The Triassic border fault in the Hampden quadrangle, Massachusetts and Connecticut (loc. 21), covers a zone as much as 1,200 m wide that is intensely broken by intersecting fault planes trending about N. 15° E. and N. 25° W. Repeated movement has resulted in zones of crush-breccia of distinct lithology which have been mapped separately by J. D. Peper. An early, strongly foliated, mottled pink and green cataclastic gneiss consists of eyes of quartz and pink altered feldspar surrounded by thin septa of chlorite and epidote. The cataclastic foliation of the gneiss trends about N. 20° W. but is warped by later faulting. A later dark-gray schistose blastomylonite fills wide (200 m) fracture zones in the mottled gneiss and locally fills the entire width of the fault zone. Later open fractures in the gneiss and blastomylonite are filled with vuggy quartz veins; locally these record variable histories of repeated opening, closing, and shearing. Late jasperoid-quartz crush-breccia, ribbed with quartz veins, is associated with broken Triassic sandstone on the downthrown (west) edge of the fault zone. This crush-breccia is spotted locally with minor chalcopyrite mineralization. Secondary copper carbonates forming drusy coatings on the sandstone were noted by R. B. Colton in 1968. Thin mappable zones of chloritized and silicified crystalline rock flank the eastern edge of the fault zone.

Great Hill syncline in Connecticut

M. H. Pease, Jr., has extended detailed stratigraphy of the Great Hill syncline southward from the Massachusetts border along the western part of the Stafford Springs quadrangle and through the southeastern part of the Ellington quadrangle, Connecticut (loc. 22). This study updates the geology of the Ellington quadrangle, mapped originally by G. E. Collins (1954). The Great Hill Formation of G. P. Eaton and J. L. Rosenfeld (1960), which is correlative with the Clough Quartzite of the standard New Hampshire sequence on the Bronson Hill anticlinorium, maintains a remarkably constant thickness of 100 to 200 ft on both flanks of the syncline in the Stafford Springs quadrangle. It persists through the Ellington quadrangle on the east flank but apparently is cut out or pinches out on the west flank in the vicinity of Browns Brook as shown by Collins. Gray schist of the Camp Jenkins Formation of Eaton and Rosenfeld (1960), which overlies the Great Hill, forms a band in the axial part of this isoclinal fold that is less than 1,500 ft wide at the Massachusetts border and widens to more than 4,500 ft in the Ellington quadrangle. The Collins Hill Formation of Rodgers and others (1959), beneath the Great Hill Formation, is largely cut out by unconformity on the east flank of the syncline but intertongues locally with felsic metavolcanic sandstone of the Middletown Gneiss. A probable local vent of mafic lava is represented in the Middletown Gneiss by a thick accumulation of massive amphibolite and amphibolite gneiss exposed in the Ellington quadrangle. These mafic rocks intertongue northward with felsic metavolcanic tuff and lava that compose most of the Middletown Gneiss in the Stafford Springs quadrangle.

Southern termination of the Merrimack geosynclinal sequence in east-central Connecticut

Reconnaissance investigation by M. H. Pease, Jr., and others in central Massachusetts and southern New Hampshire has indicated that the rocks in the Brimfield area (loc. 23) probably represent the southern extent of a thick geosynclinal sequence of middle Paleozoic rocks that lies along the general trend of the Merrimack synclinorium. In east-central Connecticut the geosynclinal sequence, at least 50,000 ft thick, is tilted steeply to the west and compressed into a relatively narrow, highly faulted belt no more than 12 mi wide. It is separated from the classic sequence of the Bronson Hill anticlinorium of Massachusetts and New Hampshire by the Monson Border fault and is cut out on the south by several thrust faults including the Eastford and Kinney Pond faults. Northward, this sequence is less compressed and lies in relatively open folds which present a much broader band of outcrop. Rocks on the west side of the Worcester basin (loc. 24) generally correspond with the lower part of the Brimfield area sequence of Connecticut. Pease also recognizes a general correspondence of the stratigraphic sequence in the Peterborough and Concord quadrangles, New Hampshire (loc. 25), to most of the sequence in the Brimfield area. Thickness comparisons are difficult to make because of the absence of measured sections in New Hampshire, but the band of outcrop is greater than 20 mi wide.

Faulting in eastern Connecticut

A high-angle fault east of the Lake Char fault in the southern part of the Plainfield quadrangle, Connecticut (loc. 26), has been traced southward at least 5 mi into the Jewett City quadrangle by H. R. Dixon. Rather than branching off the Lake Char fault, as previously interpreted, the fault probably offsets the mylonitic rocks of the Lake Char fault. The fault is marked by a number of exposures of brecciated and silicified Hope Valley Alaskite Gneiss and locally of pure quartz veins similar to but much smaller than the Lantern Hill quartz vein (Old Mystic quadrangle). It is not clear what happens to the fault in the Old Mystic quadrangle to the south, but it may represent the northern extension of the fault at Lantern Hill, offset by other faults at the southeastern side of the Preston Gabbro.

PLEISTOCENE GEOLOGY

Proliferation of glacial lakes in southern New Hampshire

Detailed surficial mapping in the Merrimack River valley from Nashua to Concord, N. H. (loc. 27), by Carl Koteff has shown that there were at least four glacial lake levels instead of just one as previously believed. The original term "glacial Lake Merrimack" is now restricted to that part of the Merrimack valley between Nashua and Manchester. A lower lake, glacial Lake Hudson, existed south of Lake Merrimack and extended across the Massachusetts border. North of Lake Merrimack, a small area was covered by glacial Lake Manchester, and from Manchester to Concord the valley was covered by glacial Lake Hooksett. An unusual aspect of these four lakes is that each was progressively higher northward. Typically in southern New England valleys, glacial lake levels either remained stationary or dropped as the northward retreating ice front uncovered lower and lower outlets. In the Merrimack valley, however, drift dams were constructed at the ice edge completely across the valley in several places, and water from succeeding lakes was diverted around these drift dams through successively higher spillways on the side of the valley. It is possible that two or more of the lakes existed at the same time.

Appreciable amounts of varved clay have been found only in Lake Hooksett deposits. Clay from this area was mined extensively for making bricks, many of which were used in the building of large mills in Manchester. The clay pits, however, have been abandoned for several decades.

New ice stillstand on Cape Cod, Massachusetts

Recent mapping in the Cotuit quadrangle (loc. 28), Cape Cod, Mass., by R. N. Oldale has delineated kamelike features

along the south shore that are higher and older than the adjacent Mashpee pitted plain. These features may correlate with other kamelike features along the north shore of Nantucket Sound from Falmouth to Chatham (R. N. Oldale and Carl Koteff, 1970). Together they may mark a major stillstand of a stagnant ice front after retreat of the last ice from Nantucket and Martha's Vineyard and before the ice reached a position approximated by the Sandwich moraine.

Reworked glacial drift, Martha's Vineyard

Study of rock lithologies and mineral constituents of sand found by C. A. Kaye in later Pleistocene moraines on Martha's Vineyard, Mass. (loc. 29), indicates that a high proportion of the material must have been reworked from earlier drift. Rock types characteristic of central and northern Rhode Island and adjacent Massachusetts are particularly abundant. Several unusual minerals in the sand component of the drift are possibly derived from western Massachusetts (C. A. Kaye and M. E. Mrose, 1965). The lithologies indicate that earlier Pleistocene ice moved S. 25° E. On the other hand, the shape of the upper Pleistocene moraines on Martha's Vineyard, as well as other indices of glacial movement (striations, drumlin orientation, and so forth) in eastern New England, point to a more southerly direction of regional ice flow. This difference can be explained if early Pleistocene ice had a center of distribution in western Quebec, late Pleistocene ice had a center in Labrador, and early drift was reworked and transported relatively short distances by the later ice sheets.

"Glacial" deposits shown to be of stream origin

Mapping by R. W. Schnabel in the uplands of the Tolland Center quadrangle, Massachusetts and Connecticut (loc. 30), has resulted in the delineation of an extensive series of high-level glacial stream deposits. In many places the upslope edge of these deposits, as well as much of the surface, is marked by an accumulation of boulders 3 to 4 ft in diameter. Two gravel pits have shown the deposits to be stream gravels which in places contain 75 percent boulder-size material. Without the gravel pits it would have been difficult to interpret this material as anything other than till.

Differential uplift in the Housatonic River valley, Massachusetts and Connecticut

A well-defined strandline near the southern end of glacial Lake Sheffield, Massachusetts and Connecticut (loc. 31), has a post-glacial tilt up to the north of about 10 ft per mi, according to W. S. Newman. Evidence from a delta at the north end of the lake, however, indicates a tilt of only 4 ft per mi there. The difference could be accounted for by a decrease in rebound amount as deglaciation proceeded from south to north.

Periglacial features in northeastern Connecticut

D. A. Goulding has found newly exposed periglacial features in the Thompson quadrangle, Connecticut and Rhode Island (loc. 32). Fossil ice-wedge or contraction-crack polygons in delta topset beds have been preserved by infilling of wind-blown sand and silt.

Pink sand in glacial terraces in the Salmon River valley, Connecticut

Mapping by D. W. O'Leary in the Moodus quadrangle, Connecticut (loc. 33), has shown that glacial terraces along the Salmon River consist of yellow sand and gravel capped by finer pink sand and gravel. The yellow sediments are derived locally from crystalline rocks whereas the pink sediments are derived from Triassic red beds to the northwest in the Connecticut River valley. This occurrence suggests that during deglaciation the ice was still high enough in the Connecticut Valley to divert outwash across a drainage divide into the Moodus quadrangle via the Blackledge River valley.

Widespread man-induced change in character of surface materials in Bridgeport area

Mapping by R. M. Barker of surficial geology in the Bridgeport quadrangle, Connecticut (loc. 34), has shown that at least 65 percent of the surface, and probably considerably more, consists of various kinds of disturbed earth. The disturbed earth includes both cuts and fills, with the fills consisting of backfill, transported natural and trash materials, or mixtures of these. The cut and fill materials replace or bury both unconsolidated surficial deposits and bedrock. Overall, the new surface materials are considered inferior to the preexisting natural materials in soil fertility, slopes, and foundation strength and as sources of aggregate or fill. Bridgeport and neighboring communities, though old, are not different in degree of urbanization from many other American cities and towns. It is possible, therefore, that a very large amount of land has been significantly degraded during the past 125 yr. Implications for future generations are disturbing.

APPALACHIAN HIGHLANDS

ADIRONDACKS

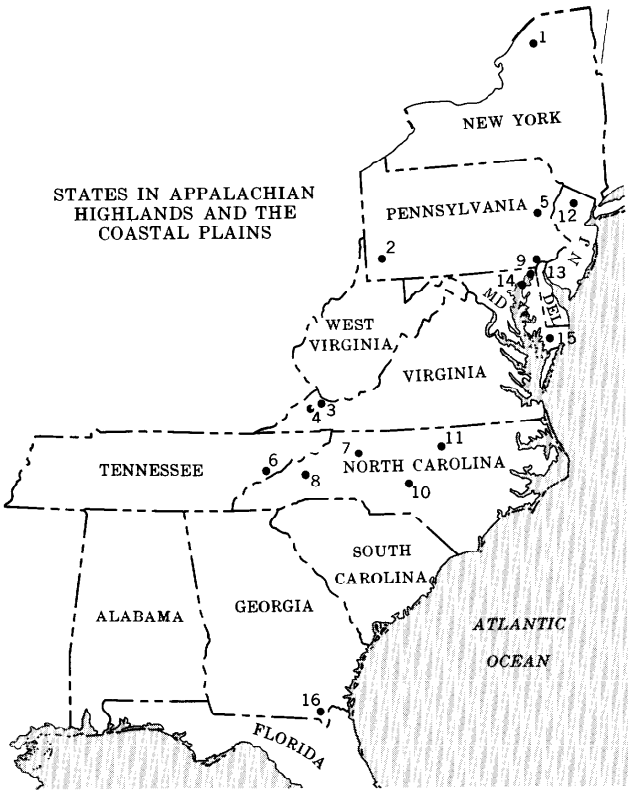
Structure of Hickory Lake "phacolith," St. Lawrence County, New York

The Hickory Lake gneiss dome (loc. 1, index map) mapped by C. E. Brown is one of 14 alaskitic gneiss bodies described about 40 yr ago by A. F. Buddington as phacoliths but now believed by most workers to have a more complex origin.

In plan the body is an elongated ellipse 2 mi long by ½ mi wide. The area surrounding the dome is completely covered by

Hickory Lake and the swamp-floored valley of Fish Creek. The dome trends north-northeast and plunges about 10° at each end. It is asymmetric, the west limb dipping 55° and the east limb about 25°. Despite the apparently simple structural picture, rocks along the dome's crest are intensely folded, and locally an earlier deformation is shown by mineral lineation diagonal to minor fold axes.

The gneiss ranges from a rose-colored magnetite-bearing alaskite to a light-gray quartz diorite. These rock types are arranged more or less concentrically with the rose-colored alaskite centrally located.



The structure of the dome is accentuated by the presence of many mafic gneiss interlayers. In the rose-colored alaskite zone, the mafic layers are biotitic layers and are less than one to a few centimeters thick. In the biotitic granitic gneiss and dioritic gneiss the layers are amphibolites less than a meter to a few meters thick. The amphibolite layers are intricately folded and broken into layers of angular blocks. One pyroxene-bearing gneiss zone contains alined, greenish, calc-silicate blocks containing diopside and garnet.

There is no parallelism between the surrounding metasedimentary rocks and the rocks in the gneiss dome. The dome is completely surrounded by an elliptical, ¼-mile-wide lowland of lake and swamp. The one outcrop found in this belt is hornblende-garnet-sillimanite gneiss containing remnants of impure marble, and most of the remaining covered interval is assumed to be marble. To the east beyond the lowland the rocks are quartzite, impure marble, and mafic gneiss. These rocks are not arranged parallel to the dome but are complexly deformed into recumbent folds overturned southward. Axes of minor folds fan through 120° including the entire northeast quadrant. This fanning could be caused by upwarping of a folded terrane by later folds like the Hickory Lake dome. The structural discontinuity that must separate the gneiss dome from the surrounding metasedimentary rocks could be a major unconformity, a prefolding thrust fault, or a boundary shear zone if the dome is diapiric.

APPALACHIAN PLATEAUS AND VALLEY AND RIDGE PROVINCES

Geologic investigations in the coal, oil, and gas region of southwestern Pennsylvania and southwestern Virginia, including stratigraphic studies by J. B. Roen and K. J. Englund and structural mapping by R. L. Miller and C. R. Meissner, continue to provide stratigraphic and structural information leading to a better understanding of the geologic environment of these fuels resources. J. B. Epstein, A. G. Epstein, and S. M. Bergström, working in eastern Pennsylvania, have unearthed paleontologic evidence confirming the exotic nature of some of the allochthonous blocks in the Hamburg klippe. A. A. Drake, Jr., has found that complex nappe system west of the Reading Prong continues to the southwest of the Allentown area. L. D. Harris has proposed a model for extreme dolomitization of the Cambrian and Ordovician strata in the Eastern United States by epicontinental hypersalinity system. G. G. Connally and J. B. Epstein are studying the deglaciation of areas in eastern Pennsylvania.

Sandstone studies, Dunkard basin, southwest Pennsylvania

A regional isopach map of the "Pittsburgh" sandstone in Allegheny, Fayette, Greene, and Washington Counties (loc. 2), prepared by J. B. Roen, shows a northwest-trending anastomosing belt of sandstone at least 60 mi long and ranging from 6 to 25 mi wide. The southwest margin of the sandstone belt is clearly defined whereas the northeast edge is in places poorly defined. The average thickness of the sandstone is about 30 ft, although locally it is as much as 80 to 100 ft thick. Thickness variation and trends shown by the map suggest a southeast source for the sand but do not preclude a northerly source. Thickness and trend lines, sinuous and bifurcating down the paleoslope, describe a sediment distribution pattern of a fluvial-deltaic complex. The sandstone distribution patterns, including shape, trend, and thickness, indicate little if any relation to the regional structure of the underlying Pittsburgh coal bed. The irregularities on the paleosurface, which controlled depositional patterns, probably resulted from differential compaction of the subjacent sediments.

Fish remains substantiate regional correlation of Upper Pennsylvanian and Lower Permian rocks

Paleontologic studies on an informal cooperative basis by Richard Lund, University of Pittsburgh, have confirmed the correlation suggested by J. B. Roen that the upper limestone members of the Washington Formation in Pennsylvania and Ohio are not the same unit (U.S. Geological Survey, 1970, p. A24). The upper limestone member of the Washington Formation of Pennsylvania was correlated by Roen with the Dilles Bottom Limestone Member of the Greene Formation (H. L. Berryhill, Jr., 1963) of Belmont County, Ohio, which is some 80 ft above the upper limestone member of the Washington Formation of Ohio. This study has shown for the first time that fossil fish remains may be used for regional correlation of the rocks in the Dunkard basin.

Deltas and barrier bars in Lower Pennsylvanian sandstones, southwest Virginia

The sandstone beds in the Pocahontas Formation (Lower Pennsylvanian) (loc. 3) form both lobate masses (deltas?) and linear masses (barrier bars?) according to K. J. Englund (1972). The lobate masses have a quartz content of about 50 to 65 percent and are elongate to the northwest. Within a lobe, lines of equal thickness show a bifurcating pattern similar to the pattern of distributary channels of a modern delta. The lobate masses merge laterally to form northwestward-thinning sandstone wedges as much as 300 ft thick. The linear masses consist of relatively pure quartz sandstone and form lenses 3 to 8 mi wide and up to 140 ft thick that extend north-northeast for about 45 mi. These lenses occur near the distal ends of the lobate sandstone masses. The well-washed character of the sand and the orientation of the linear bodies, normal to the lobate bodies (deltas?), suggest a barrier-bar origin.

Fault complex in southwest Virginia

Detailed mapping by R. L. Miller and C. R. Meissner in the Big A Mountain quadrangle, Buchanan and Russell Counties, Va. (loc. 4), has shown that pre-Pennsylvanian formations are cut by a series of major southeast-dipping thrust faults into slices, shingled one on the next. Several of these major faults have been recognized in earlier small-scale mapping, but others are identified for the first time. Big A Mountain itself, previously mapped as a syncline, is instead made up of fault slices of the resistant Clinch Sandstone and associated formations. The rocks contiguous to the Russell Fork fault, the transverse or tear fault that forms the northeast edge of the Cumberland overthrust block, are disturbed very little even though the fault has some 4 mi of displacement. In most places distortion or disturbance of the rocks along the fault extends only a few tens of feet away from the fault plane.

Exotic carbonate blocks in the Hamburg klippe, eastern Pennsylvania

Several recent workers in the Great Valley of Pennsylvania have recognized blocks of allochthonous carbonate rock floating in pelite of what has been called Martinsburg Formation. Within the so-called Hamburg klippe most investigators have tacitly assumed that the allochthonous blocks were emplaced during pelite sedimentation and came from the adjacent Cambrian through Middle Ordovician dolomites and limestones. Recent reconnaissance by A. A. Drake, Jr., has shown, however, that this did not occur, at least in the area east of the Schuylkill River. Here the most common exotic carbonate blocks are of ripple-bedded limestone that overlies ripple-bedded platy limestone and calcareous shale or thick-bedded to massive sandy calcarenite (or dolarenite). Some of the carbonate rocks are stromatolytic. At many places intraformational conglomerate of sandy limestone clasts in a sandy limestone matrix are well developed. These lithologies are repeated in cycles. It would appear, therefore, that blocks of ripple-bedded carbonate are pieces of the same carbonate terrane more fully represented by the blocks of cyclic carbonate rocks. The cyclic carbonate rock of the very large blocks is well exposed at both Crystal and Onyx Caves. None of these rocks crop out in the carbonate belt in the Great Valley.

Exposures examined by J. B. Epstein and A. G. Epstein (p. D29–D36) near Lenhartsville, Berks County, Pa. (loc. 5), within the Hamburg klippe contain blocks of carbonate rock ranging from less than ¼ in. to more than 80 ft long that have slumped into deeper water mudstones and siltstones. The blocks were derived from limestone- and sandstone-pebble conglomerate, overlain by laminated and ripple-bedded limestone, and in turn by shale. These rocks are interpreted to be turbidites. A similar interpretation was suggested by P. B. Myers (oral commun., 1972). The limestone clasts probably were transported from a shelf by turbidity currents, and later slumped.

A large collection of conodonts was recovered from the limestone by the Epsteins and identified by S. M. Bergström (p. D37–D44) of Ohio State University. These conodonts are unlike those from the autochthonous shelf carbonate rocks of eastern Pennsylvania which belong to the North American midcontinent faunal province. The collection is unique because it contains the only known North Atlantic faunal province conodonts of this age in the United States and is the most complete collection in North America to date. The conodonts in the collection are identical to conodonts of the *Prioniodus elegans* Zone at the boundary between the Hunnebergian and Billingenian substages of the Laptorian Stage in the lower Arenigian (Lower Ordovician) of the Balto-Scandic succession. Limestones similar to those exposed at Lenhartsville are unknown in the Beekmantown Group (Lower Ordovician) of the Great Valley of eastern Pennsylvania. Beekmantown conodonts collected by J. B. Epstein near Martins Creek, Northampton County, Pa., have been tenta-

tively identified by J. W. Huddle as of the midcontinent province. Such faunal provincialism between European and midcontinent North American conodonts from one small area strongly suggests that the limestones near Lenhartsville originally slumped down from sediments that lay somewhere to the east and reached their present position by northwestward thrusting during the Taconic orogeny when the Hamburg klippe was emplaced (U.S. Geological Survey 1971, p. A27). If this thesis is correct, continental drift might be the explanation of the initial juxtaposition of the rocks of the two provinces.

Relations of Hamburg klippe and slate-belt Martinsburg Formation, eastern Pennsylvania

The graywackes in the Hamburg klippe, including those of Shochary Ridge, Berks County, Pa. (loc. 5), are sufficiently different from graywackes in the Martinsburg Formation of the slate belt to the east, judging from initial petrographic examination by J. B. Epstein, to suggest that the slump blocks of carbonate rocks reported by many workers in the klippe were not emplaced in host rocks of the Martinsburg Formation. A marked structural break between the slate-belt rocks of eastern Pennsylvania and the rocks of Shochary Ridge was suggested on paleontological grounds by J. B. Epstein and W. B. N. Berry (U.S. Geological Survey, 1970, p. A26) and on structural and stratigraphic grounds by A. A. Drake, Jr., and J. B. Epstein (U.S. Geological Survey, 1971, p. A27). The petrographic data support the conclusion that the Hamburg klippe and slate-belt Martinsburg were brought together on a fault of many miles of displacement. This conclusion may also explain why three members have been mapped in the slate-belt Martinsburg and only two members have been mapped in the so-called Martinsburg of the Hamburg klippe, a source of controversy for more than 40 yr.

Stacking of nappes west of Allentown, Pennsylvania

Detailed geologic mapping in the Catasauqua and Cementon quadrangles (loc. 5) by A. A. Drake, Jr., has delineated two areas of outcrop of Allentown Dolomite (Upper Cambrian) that is right side up in a general terrane of Beekmanstown Group (Lower Ordovician) and Jacksonburg Limestone (Middle Ordovician) that are inverted. The Allentown is in fault contact with the surrounding rocks, largely Epler Formation (Lower Ordovician) and Jacksonburg Limestone. It appears, therefore, that the Allentown belongs to the subjacent, largely buried Lyon Station–Paulins Kill nappe (U.S. Geological Survey, 1969, p. A28) showing through windows in the Musconetcong nappe. The situation here is similar to that in the Paulins Kill valley near the Delaware River (A. A. Drake, Jr. and others, 1969) where the upper limb of the lower nappe crops out, although north and west of Allentown the frame is carbonate rather than pelitic rocks of the Martinsburg Formation.

Glacial deposits in eastern Pennsylvania

In the Saylorsburg area, Monroe County (loc. 5), G. G. Connally and J. B. Epstein have recognized two Wisconsin tills and the deposits of seven Wisconsin deglaciation sequences. Near Lehigh Gap, Northampton and Carbon Counties, Epstein has identified a Wisconsin valley train, an Illinoian(?) outwash terrace, prelllinoian(?) outwash, and even older and higher remnants of terrace gravels. Preliminary X-ray diffraction analyses of the clay-sized minerals in the deposits suggest that, with increased age and weathering, chlorite is removed, illite is degraded, and vermiculite and kaolinite are produced.

Dolomitization model for Upper Cambrian and Lower Ordovician carbonate rocks in the eastern United States

Existing models for dolomitization emphasize that penecontemporaneous dolomitization can occur in both subtidal and supratidal settings if the necessary chemical and physical factors favorable for the development of magnesium-rich hypersaline waters exist. Present-day shallow water hypersaline environments that have the potential to produce dolomite without deposition of more soluble evaporate minerals are found in Shark Bay, Australia, and on the Bahama Bank. These present-day hypersalinity systems are characterized by nearly vertical isosalinity layers that increase in salinity landward from the open ocean and show little or no relationship to bottom topography. A similar but large-scale epicontinental salinity system may have developed on the Late Cambrian and Early Ordovician carbonate continental shelf. It is suggested by L. D. Harris as a result of studies on the Knox Group of eastern Tennessee (loc. 6) that the present distribution of limestone and dolomite in the delta from Canada to Mexico was closely keyed to a shoreward-increasing salinity gradient, so that a natural progression from a more normal marine limestone phase to a transition phase to a dolomite phase occurred.

BLUE RIDGE AND PIEDMONT

Regional structural and stratigraphic relations in the southern Blue Ridge are well displayed in the recently published map of the Knoxville 2-degree quadrangle by J. B. Hadley and A. E. Nelson (1971). This map is a good example of how much geology can be shown at 1:250,000 scale. Mapping of the Winston-Salem 2-degree quadrangle by G. H. Espenshade, D. W. Rankin, and K. W. Shaw extended to the northeast the work of Hadley and Nelson. Identification of major structural blocks, the relations between them, and their characteristic internal fabric are one of the principal values of this type of mapping. Such maps by synthesizing existing data provide a background for more detailed geologic studies and for land-use planning. Isotopic age determinations by M. W. Higgins on zircons from trondhjemite dikes in the Knoxville quadrangle provide a possible minimum age for the Great Smoky Group.

Higgins in collaboration with Isidore Zietz and others has begun a program of geologic interpretation of aeromagnetic data from the northern Piedmont and Coastal Plain. This has already resulted in identification of a new Baltimore Gneiss dome and in a structural interpretation of the origin of upper Chesapeake Bay. (See "Aeromagnetic anomalies reveal major features in the northern Piedmont" in this section.)

Structural studies in the Blue Ridge and Piedmont, North Carolina

With completion of geologic mapping of the Winston-Salem quadrangle by G. H. Espenshade, D. W. Rankin, and K. W. Shaw (U.S. Geological Survey, 1971, p. A30), Espenshade has modified his preliminary interpretation of the geology to the south of the Sauratown Mountains anticlinorium, Davie, Forsyth, and Yadkin Counties, N.C. (loc. 7). It now appears that the inner Piedmont belt of synorogenic granite, migmatite, and sillimanite-grade schist and gneiss, which borders the southeast side of the Brevard zone for several hundred miles from Alabama to central North Carolina, comes to an abrupt end at the southwestern nose of the Sauratown Mountains anticlinorium where it is probably in thrust contact with the Ashe Formation (upper Precambrian). The belt of rocks to the east of the inner Piedmont consists of mica gneiss and schist intruded by a complex of late-orogenic mafic and granitic plutonic rocks and is evidently the northeasterly continuation of the Charlotte belt. The strike of the main part of the Charlotte belt is about N. 30° E., but at the anticlinorium the strike is sharply deflected to N. 60° E., parallel to the anticlinorium. The contact between the Charlotte belt and the Ashe Formation on the southeastern limb of the anticlinorium is inferred to be a Triassic normal fault that extends between the northwest border faults of the Dan River and Davis County Triassic basins.

A petrofabric analysis by G. H. Espenshade of foliation, lineation, and fold axes in an area of about 2,100 sq mi in the Piedmont part of the Winston-Salem quadrangle suggests thrusting as the major movement sense along this part of the Brevard zone, rather than strike-slip movement. This analysis extended northeastward the analysis made by Bruce Bryant and J. C. Reed, Jr. (1970).

Within the Brevard zone, foliation planes trend in general with the strike of the zone and dip 60° SE. Foliation in the Blue Ridge thrust adjacent to the north side of the Brevard zone dips more gently about 50° SE. South of the Brevard zone in the inner Piedmont belt, dip of foliation decreases progressively to about 30° SE. Similar relations were also found by Bryant and Reed. Mineral lineations, fold axes, and some axes of partial girdles of foliation poles are about parallel and plunge very gently, generally about in the *b* fabric axis.

The structural style of the Sauratown Mountains anticlinorium is in sharp contrast with that of the other major structural units—the Blue Ridge thrust block, Brevard zone, and the inner Piedmont belt.

Older Precambrian rocks are exposed farther east in the Sauratown Mountains anticlinorium for a distance of more than 40 mi along the axis and as much as 14 mi across the anticlinorium. Foliation planes curve around the anticlinorium and dip much more gently than in the Brevard zone, about 25° to 30° on each limb of the fold. Some mineral lineations and most axes of partial girdles of foliation poles trend obliquely downdip. In places, perhaps due to large-scale cross folding in the anticlinorium, several partial girdles of foliation poles are superimposed.

Lead-uranium ages on trondhjemite dikes and ages of Great Smoky Group, western North Carolina

Lead-uranium ages run by M. W. Higgins on three zircons and two sphenes from trondhjemite dikes collected by J. B. Hadley in the northeastern part of the Knoxville 2-degree quadrangle, North Carolina (loc. 8) (J. B. Hadley and A. E. Nelson, 1971; J. B. Hadley and Richard Goldsmith, 1963) suggest a possible (preliminary) age of about 950 m.y. as minimum for the Great Smoky Group of the Ocoee Supergroup. The dikes cut the basement complex (1,100–1,300 m.y. old) and the Great Smoky Group but are not found cutting younger rocks. The two sphenes from two different dikes gave nearly concordant ages of 340 to 350 m.y. that are interpreted as being ages of metamorphism. The three zircons gave discordant ages. Using the essentially concordant sphene ages of 340 to 350 m.y. for a lower intercept on a concordia plot, the zircon for which the best data are available plots on a chord with an upper intercept of about 940 to 860 m.y. The other two zircon ages plot slightly below this chord, but whether this is due to experimental error or because part of the samples were relict zircons (1,100–1,300 m.y. old) from the basement is uncertain. Hadley reports that xenoliths in the dikes are very rare. This report, together with the thinness of the dikes and their composition, suggests that the zircons are probably not relict from the basement. Higgins and Hadley tentatively conclude that 940 to 960 m.y. represents the age of intrusion of the dikes and thus places a minimum (upper) age on the Great Smoky. This age is reasonable geologically.

Idiosyncrasies of intrusive rocks within the Carolina slate belt

At least two ages each of felsic and mafic intrusive rocks occur near the Gold Hill fault in the slate belt of central North Carolina, according to A. A. Stromquist. The map distribution of one felsic rock is indicated by a reddish soil containing tiny flakes of mica visible with a hand lens and locally containing saprolitic porphyroblasts of feldspar 2 in. across in a quartz-feldspar-biotite groundmass. Radiometric highs correlate with and corroborate the map pattern of this rock. The other felsic rock consists of quartz, oligoclase, and microcline plus accessories. Although the rock is fresh looking and is quarried for building stone, it is incipiently sheared, and interstitial

ferromagnesian minerals are altered to garnet, biotite, chlorite, sericite, epidote, and calcite. Uralitic gabbros east of the Gold Hill fault are similar in composition and have many sill-like relations to the volcanic-sedimentary rocks of the slate belt; the gabbros probably were comagmatic with the andesitic basalts of the slate-belt rocks. Gabbro and diorite that intrude schistose and gneissose volcanic-sedimentary rocks west of the Gold Hill fault are not sill-like or uralitic and must be related to a later intrusive episode or to a period of regional metamorphism younger than that of the uralitic gabbro.

Petrologic and gravity studies in the slate belt of North Carolina

Field and petrographic study by V. M. Seiders of volcanic rocks of the Carolina slate belt near Asheboro, Randolph County, N.C. (loc. 10), suggests a strongly bimodal distribution between mafic and felsic rocks: andesites are largely absent. Nearly 40 new chemical analyses show that most volcanic rocks have SiO_2 contents below 54 percent or above 65 percent. Practically the only analyses with SiO_2 contents between 54 and 65 percent are of volcanic mudstones and of volcani-clastic rocks containing both mafic and felsic debris.

Further north in the slate belt in the Roxboro-Henderson area, Person and Granville Counties (loc. 11), a contour gravity map based on 2,200 stations has been completed. Interpretation by J. W. Allingham of the map in conjunction with measurements made on densities of rock units shows that the subsurface shapes of mafic and felsic plutons are highly irregular.

Aeromagnetic anomalies reveal major features in the northern Piedmont

Aeromagnetic anomalies in northeastern Delaware and southeastern Pennsylvania (loc. 9) shown on the map recently compiled by Isidore Zietz and J. R. Kirby suggest the presence of a previously unknown Baltimore Gneiss dome. Limited fieldwork by M. W. Higgins shows that Cockeysville Marble and Setters Formation crop out locally around the edge of the dome, coinciding precisely with the gradient at the edge of the magnetic anomaly.

To the south, preliminary interpretation by Higgins and Zietz of a large aeromagnetic low that coincides with the northeastern part of Chesapeake Bay (loc. 14) suggests that the bay may be underlain by Baltimore Gneiss and by a sedimentary basin in the Coastal Plain rocks. The eastern edge of the magnetic anomaly is probably a fault. This fault may have determined the present position of the bay.

Basalts in First Watchung Mountain, Paterson, New Jersey

Detailed field petrologic studies by G. T. Faust were made in a cut for U.S. Highway 80 along Garrett Mountain in West Paterson and Paterson, Somerset and Union Counties, N. J. (loc. 12). The cut follows the former trackway of the Delaware, Lackawanna and Western Railroad. Here the pillow basalts of the upper flow unit are well exposed. The cut is close to the Lower New Street Quarry, famous for its specimens of zeolite, prehnite, pectolite, and stevensite. Whereas the base of the upper flow unit is heavily mineralized, the entire lower flow unit of First Watchung Mountain, in the Paterson area, is virtually nonmineralized.

The relative abundance of minerals in the mineralized base of the upper flow is as follows:

Abundant:

- chlorite (appears to be the commonest species)
- anhydrite (largely represented by crystal cavities indicating its former abundance)
- prehnite
- pectolite-stevensite
- laumontite

Much less abundant:

- albite
- amphibole-variety byssolite
- analcime
- apophyllite
- chabazite
- datolite
- gmelinite
- glauberite (inferred from crystal cavities)
- gypsum
- heulandite
- mesolite
- natrolite
- stilbite
- thomsonite

Faust found that joint systems in the exposed section of basalt in First Watchung Mountain, at the northernmost end of Garrett Mountain, formed a sequence as follows: a very thin zone of vesiculate basalt, a thin zone of curvilinear-jointed basalt, a very thick zone of columnar-jointed basalt with a curvilinear aspect, a thin zone of curvilinear-jointed basalt, and a thin zone of massive basalt at the top of the exposed section.

COASTAL PLAINS

Carolina Bays in Maryland revisited

The nearly flat northern part of the Delmarva Peninsula in Cecil County, Md. (loc. 13), has abundant round to elongate depressions up to several hundred feet across and typically shallow (2–5 ft in depth). Most of these depressions are clustered just slightly below the undissected surface of Pleistocene(?) alluvium and are partially connected by a poorly developed drainage system. A few are on the Potomac Group of late Early to early Late Cretaceous age. L. C. Conant noted that most of the depressions are alined east-northeastward paralleling the regional strike of the underlying Cretaceous strata and are almost wholly restricted to that area where the alluvium overlies beds of the Potomac Group and Magothy Formation.

Similar depressions are common in the Coastal Plain from New Jersey to the Gulf of Mexico. Unlike many of these, the depressions have no raised rims. Many explanations have been offered for the formation of these depressions, but the one

favored by Conant is virtually the same proposed by W. C. Rasmussen (1959a, b). Essentially this interpretation involves the collection of waters in low-lying areas where the water then seeps downward into an underlying porous strata. As the water passes through the strata, the finer clasts, silt and clay, are removed causing subsidence of the surface. Organic acids produced by the decaying organic matter in the swampy low-lying areas promote the removal of additional material as suggested by L. L. Smith (1931).

As most of the depressions are clustered in broad shallow valleys, it may be that, where conditions were most favorable, their abundant development caused a general lowering of the surface. A virtually complete gradation can be seen between isolated depressions on the undissected surface to broad irregular valleys where drainage lines connect closely spaced ones. Conversely, they may have formed in such abundance locally because a broad drainage area has removed some of the less permeable uppermost alluvium and has permitted easier downward drainage.

Delmarva Peninsula

The coastal sediments in the Delmarva Peninsula, Delaware, Maryland, and Virginia (loc. 15), were deposited generally in a transgressive barrier–back barrier environment. At least three such transgressions have been recognized: the present (Holocene) transgression which is cutting into the peninsula, a second associated with Assateague Island and representing a possible middle Wisconsin high-sea stand, and a third unit at elevations up to 40 ft above sea level and extending across the southern part of the peninsula to the Pocomoke River. This is a distance of about 10 mi from the present coast, as determined by J. P. Owens and C. S. Denny, and seems to be the maximum incursion of the transgressive beds of late Quaternary age onto the peninsula.

Detailed investigations were also made by J. P. Owens on the Beaverdam Sand, a much older formation, which wherever seen appears to be a beach or nearshore marine deposit. This unit underlies nearly half the southern part of the main Delmarva Peninsula. The outcrop pattern of this unit is arcuate with the inner rim extending from Princess Anne, Md., to Milford, Del. The sand does not resemble the sands of the transgressive barrier–back barrier sequences but tends to be mostly a sheet deposit. This unit appears to have been deposited during a large-scale regression and is not too dissimilar to the Cohansey Sand of New Jersey of Miocene(?) and Pliocene(?) age.

Studies of the dune sands by C. S. Denny and Karl Stefansson indicate that the sands are particularly widespread in the peninsula from west of the Pocomoke River to near Salisbury, Md. These dunes cover large areas and are particularly interesting because gibbsite is widespread in the shallow-soil profiles formed on them. What this mineralogy represents is not known, but in the past it has been used to connote very warm, wet conditions. In addition, most of the dunes have a parabolic form with the tails pointing to the northwest. Prevailing wind direction, therefore, would have been from the northwest.

A study of the sediments within the major bays (Chesapeake and Delaware) was made to provide data as to the time of bay filling, the climate prevailing during this period, and the type of sediment being carried by the major rivers at this time. Cores through most of the upper Wisconsin–Holocene fill indicate that both bays have essentially the same mineralogy according to Karl Stefansson. Clays are composed of all the major clay groups in roughly equal proportions; in other words, the sediment is very immature. Palynological studies by L. A. Serkin of Adelphi University of the clayey silts indicate little variation from bottom to top (mostly oak-hickory forests, or C pollen zone of the New England pollen zonation). These data suggest major bay fill did not take place until well into the latest Wisconsin or earliest Holocene time and that the estuaries filled rather rapidly after this time.

Chattahoochee anticline and Ochlockonee fault discounted

An analysis of original stratigraphic work and a review of the geologic literature on structural features in southwestern Georgia (loc. 16) by S. H. Patterson and S. M. Herrick (1971) show that several features have been proposed and given formal names in published reports without adequate evidence for their existence. Structural features that should not be considered valid include the Chattahoochee anticline and the Ochlockonee fault.

CENTRAL REGION AND GREAT PLAINS

KENTUCKY

Geologic mapping of State

A cooperative project with the State, begun in 1960, was more than 70 percent completed by May 1, 1972, when 414 geologic maps had been printed (fig. 1), another 51 maps had been approved for publication, and an additional 33 were undergoing editorial review. Geologic mapping was in progress in more than 70 quadrangles. About 710 maps will be published to cover the 763 7½-minute quadrangles that are wholly or partly within the State. The geologic maps are printed on recent editions of topographic base maps of quadrangles, at 1:24,000 scale, and published in the geologic quadrangle map series.

Crossbedding studies of Ordovician limestone in Blue Grass region of central Kentucky

According to a study by S. V. Hraber (1971) (graduate student, Univ. Cincinnati), E. R. Cressman (U.S. Geological Survey), and P. E. Potter (professor, Univ. Cincinnati) of the Tanglewood Limestone Member of the Lexington Limestone

STATES IN CENTRAL REGION AND GREAT PLAINS

(Ordovician) of the Blue Grass region, Kentucky (loc. 1, index map), crossbedding orientation in calcarenite of the Tanglewood is bimodal with the two modes 180 degrees apart. The crossbedding and its relation to the configuration of the Tanglewood suggest that the member was a bank along the western edge of a northwest-trending limestone shelf which stood above adjacent areas that received finer sediments. The bimodality of the crossbedding resulted from deposition by tidal currents.

Rockford Limestone in Kentucky

Geologic mapping by R. C. Kepferle in Jefferson County, Ky., reveals that, contrary to earlier opinion, the Rockford Limestone of Early Mississippian age (Kinderhookian) extends from southern Indiana, across the Ohio River, and into the Louisville area (loc. 2). Where exposed in the Louisville West quadrangle, the formation consists of as much as 2½ ft of greenish-gray ferroan, very glauconitic dolomite that weathers to an orange-brown layer resembling iron oxide and siderite.

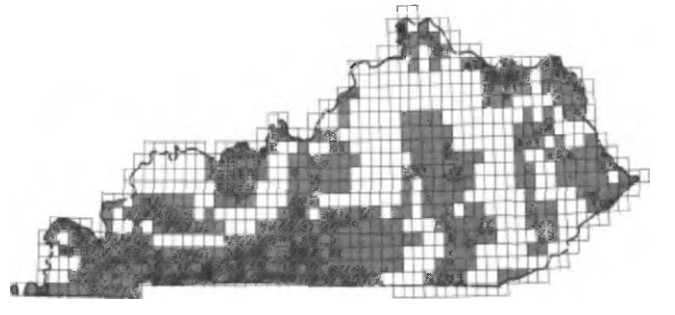


Figure 1.—Published geologic quadrangle maps (patterned area) of Kentucky as of May 1, 1972; small squares are 7½-minute quadrangles.

Members of the Borden Formation in north-central Kentucky

R. C. Kepferle (1971), in a review of the stratigraphy of the Borden Formation (Mississippian) in north-central Kentucky (loc. 3), notes that the formation consists of the New Providence Shale, Nancy, and Muldraugh Members of widespread extent and of the Kenwood Siltstone and Holtsclaw Siltstone Members of less widespread extent. Kepferle redefines the Holtsclaw and changes the names of the Kenwood and Holtsclaw to reflect their dominant lithology; previously, each unit had been designated as a "sandstone."

Kidder Limestone, a new member of the Monteagle Limestone in Kentucky

Geologic investigations by R. Q. Lewis, Sr. (1971), in south-central Kentucky (loc. 4) show that the Monteagle Limestone of Late Mississippian age is divided into a lower member, known as the Ste. Genevieve Limestone Member, and an upper member which Lewis names the Kidder Limestone Member.

Age of Pennington Formation in southeastern Kentucky

Palynological studies by R. M. Kosanke and stratigraphic investigations by E. K. Maughan indicate that the lower part of the Pennington Formation in the Roxana quadrangle (loc. 5), southeastern Kentucky, is Mississippian in age and that the upper part could be either Mississippian or Pennsylvanian in age.

Correlation of coal beds of Pennsylvanian age in southeastern Kentucky

On the basis of stratigraphic studies supported by palynomorphic data provided by R. M. Kosanke, A. J. Froelich determined that in the Middlesboro area (loc. 6), southeastern Kentucky, several coal beds have been erroneously correlated across the Rocky Face fault which trends north-northwesterly across the Middlesboro syncline. A coal bed near Middlesboro, on the southwest side of the fault, is about 250 ft higher stratigraphically than its previously supposed equivalent on the northeast side.

Sandstone caves in southeastern Kentucky

W. L. Newell (USGS) in cooperation with A. E. Godfrey of Vanderbilt University has found that development of shelter caves in silica-cemented sandstone of the Lee Formation on Cumberland Mountain (loc. 7), southeastern Kentucky, is largely due to leaching of the silica cement by groundwater migrating through the sandstone.

MICHIGAN

Portage Lake Lava Series of Isle Royale National Park, Michigan

A sequence of basaltic lava flows and interbedded sedimentary and pyroclastic rocks over 10,000 ft thick is exposed on Isle Royale (loc. 8) in northern Lake Superior. This sequence is correlative with the Portage Lake Lava Series, of Precambrian (middle Keweenawan) age, on the Keweenaw Peninsula on the opposite side of the lake. Geologic mapping on Isle Royale by N. K. Huber (1971a,b), in cooperation with the National Park Service, indicates that certain individual flows or groups of flows can be identified and traced in the field on the basis of their texture or other distinctive characteristics and that these key horizons and associated sedimentary zones provide stratigraphic and structural control within the volcanic sequence on the island.

The Portage Lake Lava Series on Isle Royale does not appear to overlap stratigraphically the lower part of the Keweenawan volcanic sequence represented by the North Shore Volcanic Complex of Gehman (1958) in Minnesota on the north side of Lake Superior, and there may be a stratigraphic break between them. Moreover, the North Shore Volcanic Complex was the probable source terrane for most of the clastic debris of the interbedded sedimentary rocks in the Portage Lake Lava Series on Isle Royale and thus would have been subjected to erosion at the margin of a subsiding basin at the same time that the Portage Lake Lava Series was being deposited in the central part of the basin.

The lava flows of the Portage Lake Lava Series are flood basalts that were erupted from a major rift zone whose axis trends in an arcuate pattern through Lake Superior. Similar flood basalts underlie most or all of a belt nearly 100 mi wide and over 1,000 mi long. The depositional basin subsided as it was being filled; during intermittent periods of volcanic quiescence, clastic debris was swept into the basins from the margins to form the sedimentary deposits interbedded with the lava flows. When volcanism ceased, the trough continued to subside during the time of deposition of the Copper Harbor Conglomerate and other Keweenawan sedimentary rocks.

Structure of Keweenawan lava province

According to W. S. White, the Portage Lake Lava Series apparently accumulated in a structural basin confined to the central part of the Lake Superior area (loc. 9). The pattern of gravity highs including the midcontinent gravity high suggests that the whole Keweenawan lava province represents a series of such basins. The basins form a linear belt that is characterized by mafic lavas and is due to a type of continental rift that contrasts with the typical east African rift valley in that lavas are more prominent and graben structure is not pronounced.

Precambrian lava beds near the east end of the Gogebic Range

Ellipsoidal structures in lower, middle, and upper Precambrian lava beds are found by V. A. Trent to be larger and more numerous in the vicinity of a wrench-fault zone near the east end of the Gogebic Range (loc. 10) in northern Michigan. Trent suggests that shallow marine conditions predominated throughout much of Precambrian time; slopes of the sea floor were low to moderate. The lava was periodically extruded through fractures near or within the major fault zone.

East Gogebic Range wrench faulting

Although the Gogebic Range (loc. 10) is a monocline over most of its 78-mi length, it is tightly folded near the east end. Mapping by V. A. Trent and W. C. Prinz during the past several years has shown that a large tightly closed asymmetrical anticline near Wolf Mountain is separated from close-folded Marquette Range Supergroup strata to the east by a northeast-trending wrench-fault zone. Drill-hole data indicate a separation of about 10,000 ft in beds of Ironwood Iron-formation and Palms Quartzite. Complementary to the asymmetrical fold is a prominent fracture system that radiates from a focal point immediately to the east. Faults are marked by strong topographic and aeromagnetic lineaments and by mylonitized lower Precambrian rock. Both fold and fracture systems were developed by compressive stresses in the crust during the Penokean orogeny at the end of "Animikie" time.

Chlorite-biotite isograd in the Marquette synclinorium

A chlorite-biotite isograd, mapped by G. C. Simmons across the Marquette synclinorium (loc. 11), indicates that the most recent major thermal metamorphism postdates the formation of the synclinorium. The position of the isograd confirms the local presence of two of the metamorphic zones mapped by H. L. James (1955) around a node in the Republic district near the west end of the Marquette synclinorium.

Metadiabase sills in the Negaunee Iron-formation

Two metadiabase sills near the middle of the Negaunee Iron-formation in the Marquette synclinorium (loc. 11) have been discovered by G. C. Simmons. These sills are additional to four previously reported by J. E. Gair and G. C. Simmons (1969). Because the Negaunee Iron-formation is more than 1,000 ft thick and contains few reference horizons, these planar bodes are particularly valuable as markers that are useful in interpreting the structural details of the Marquette synclinorium.

Similarities of anomalies based on aeromagnetic and dip needle surveys in Michigan

Compilations by C. E. Dutton show that location, trend, and persistence of magnetic anomalies (including some indicated

by only two scale subdivisions) based on dip-needle surveys made during 1910-14 in the western part of the northern peninsula of Michigan (loc. 12) along north-south lines at intervals of half a mile agree very favorably with anomalies based on aeromagnetic surveys made during 1962-63 along north-south lines at intervals of a quarter of a mile. This favorable agreement in Michigan suggests that data from dip-needle surveys of comparable quality made during the early 1900's in Wisconsin may prove equally reliable in defining magnetic anomalies.

Penokean structural sequence in northern Michigan

Detailed structural studies by W. F. Cannon in the Marquette Range (loc. 13) combined with compilation of regional structural data from published reports suggest that Penokean deformation in northern Michigan occurred in two stages. During the first stage Precambrian X sedimentary rocks were deformed by compressive stresses probably resulting from regional gravity sliding; underlying Precambrian W basement rocks were not deformed. During the second stage the rocks were block faulted, and due to vertical movements along faults bounding blocks, overlying Precambrian X rocks were refolded. The second stage of folding produced the regional structures including the synclinal and monoclinal iron ranges, but the first stage produced much of the smaller scale deformation in the Precambrian X rocks. Folds of the first stage trend west and northwest, and folds of the second stage have widely divergent trends.

Gravity studies aid structural interpretations

Gravity studies by W. F. Cannon (USGS), in cooperation with John Klasner of Michigan Technological University yield approximations of depth and shape of synclinal structures in Marquette and Baraga Counties (loc. 13), Mich. The structures consist of nearly isoclinal downwarps of Precambrian X sedimentary rocks including iron-formation in grabens that displace Precambrian W basement rocks. Comparison of observed gravity profiles with those profiles derived by computer from inferred density models indicates that approximate depth to basement is (1) 5,000 ft in the Republic syncline about 1½ mi northwest of the plunging keel of the syncline, (2) 8,000 ft in the Marquette synclinorium near the Humboldt mine and 3,500 ft about 10 mi to the west near the Michigamme mine, and (3) 2,000 ft in the narrow syncline about 7 mi west of Republic. The success of this method in yielding geologically reasonable determinations of depth to basement rocks suggests that it may be a generally useful tool in approximating syncline amplitudes in areas where very dense rocks, such as iron-formation, lie within the syncline.

NEBRASKA

Geologic map of southeastern Nebraska

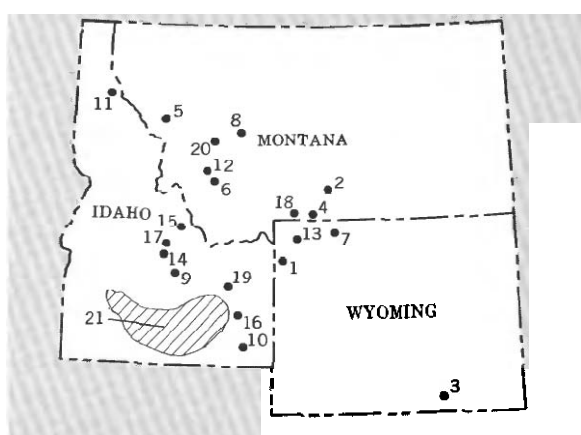
Data from test-hole logs, published and unpublished maps, and field notes from the files of the Nebraska Geological Survey were used by R. R. Burchett, V. H. Dreeszen, and E. C. Reed of the Nebraska Geological Survey and G. E. Prichard of the U.S. Geological Survey in compiling a bedrock geologic map (Burchett and others, 1972) of part of southeastern Nebraska, (loc. 14). The map, which also shows the combined thickness of Quaternary surficial deposits of loess, alluvium, lake sediments, and valley fill is at a scale of 1:250,000.

NORTHERN ROCKY MOUNTAINS

MINERAL-RESOURCE STUDIES

Gold in Cretaceous conglomerates of northwestern Wyoming

Gold-bearing conglomerates have been identified by J. D. Love in several Cretaceous formations in Grand Teton National Park (loc. 1, index map). A unit of quartzite boulder conglomerate 25 ft thick in the Bacon Ridge Sandstone contains a small amount of flour gold and is overlain by many zones of shale and siltstone that contain marine and brackish water fossils of middle Niobrara age. Some of the quartzite boulders are 18 in. in diameter. In the Meeteetse Formation, which is several thousand feet higher in the Cretaceous section, two or three other units of quartzite boulder conglomerate also contain flour gold. These conglomerates show that their source, an uplift 50 mi northwest, was eroded to the Precambrian during middle Late Cretaceous time. At least one of the conglomerates, the lowest, was deposited in a near-marine environment.



NORTHERN ROCKY MOUNTAIN STATES

Basal zone of Stillwater Complex, Montana

Mapping of the Stillwater Complex by N. J Page and W. J. Nokleberg (loc. 2) shows that the geologic relations of the

basal zone, the site of comagmatic mineralization by copper, nickel, and platinum, differ along its strike. These differences influence the search for ore deposits. In the eastern part, quartz monzonite dated at 2.7 b.y. intrudes the basal zone. Intrusion of the quartz monzonite may have removed some of the basal zone by assimilation or stoping and may have remobilized the sulfide minerals. In the middle part, the basal zone is overthrust by metasedimentary rocks with a maximum age of 3.1 b.y. that were emplaced on a south-dipping fault plane. The search for ore requires exploration below this thrust plate. The basal zone in the western part has an intrusive contact with the metasedimentary rocks. Although the structure is simple, mineral exploration is complicated by high relief and a terrain largely covered by glacial deposits.

Gold and silver in the Medicine Bow Mountains

M. E. McCallum reports that low-grade mineralization is associated with northwest-trending faults and with east-trending shear zones in the Keystone quadrangle of Wyoming (loc. 3), especially where the faults and shear zones intersect. Copper minerals are most abundant, but gold-bearing iron sulfides are found locally, and silver-bearing galena occurs in veinlets up to 1½ in. thick at one place along a fault.

Magnetic anomalies at Cooke City

Of the several magnetic anomalies shown on regional aeromagnetic maps around Cooke City, Mont. (loc. 4), one coincides with a diorite stock on Scotch Bonnet Mountain and Sheep Mountain that has been studied by J. E. Elliot. The principal mineralization of this district is found on the southwest and south flanks of this stock. A second anomaly to the northeast at Goose Lake is centered on a copper-platinum prospect in a syenite stock. Still other magnetic anomalies northwest of Cooke City coincide with known intrusives and with mineralized ground associated with them.

Copper in rocks of Belt age

Rocks of Belt age (1,450–850 m.y. ago) contain anomalous amounts of copper throughout the world. A preliminary estimate of the amount of stratabound copper in the Belt rocks of Montana, Idaho, and Washington (centered at loc. 5) that could have been available for reconcentration into ore by geologic processes has been made by J. E. Harrison. The estimate is based largely on new Belt stratigraphic and geochemical data that have been accumulated over the past 3 yr by Harrison and by M. R. Mudge, R. L. Earhart, and J. D. Wells. The stratabound copper occurs principally as chalcocite, bornite, and some chalcopyrite in certain rock units, most commonly in the green chloritic beds and the white quartzites. The concentration of copper in the green beds ranges from about 10 to about 7,000 ppm in samples 1 ft thick. Assuming that the copper in the green beds is largely diagenetic and that these beds are the principal sources for geologic reconcentration, Harrison estimates that about 3 percent of the Belt rocks contain source beds that average 500 ppm. The 400,000 cu mi of sediment in the original Belt basin therefore contained an average of about 165,000 tons of copper per cubic mile.

The stratabound copper deposits at Trout Creek, Mont., in the northern part of the Belt basin, are restricted to the quartzitic rocks of the Revett Formation of the Belt Supergroup, according to mapping by A. B. Griggs. The linear outcrop of the Revett in this area is more than 100 mi long, the greater part being exposed in the limbs of a north-plunging anticline west of the Clark Fork River. The remainder is in a fold of the same trend east of the river. The outcrop pattern of the Revett Formation is complicated in some places by faulting. Several of the copper deposits are being actively explored, each along distances of a mile or more, either by drilling or by geochemical and geophysical methods.

J. D. Wells has collected five samples from green calcareous argillite in a single square mile of the Miller Peak Formation of the Belt Supergroup 8 miles west of Alberton, Mont., in the center of the Belt basin. Equivalent beds in the eastern part of the Belt basin contain stratabound copper. Beds and fault zones ranging from 1 to 10 ft across were sampled. The samples are stained with malachite and iron oxide and contain from 0.15 to 1.5 percent copper. Anomalous amounts of barium, mercury, and silver accompany the copper. The area sampled lies on the Lewis and Clark line along an eastward extension of the Coeur d'Alene mineral belt.

STRUCTURAL STUDIES

Fold patterns in the Hecla district

Intricate fold patterns have been identified by E-an Zen in the Hecla mining area (loc. 6) by reinterpretation of stratigraphic relations previously attributed to faulting. The so-called Great fault was based on the erroneous assignment of the Lodgepole Limestone (Mississippian) to the Jefferson Formation (Devonian). The fault trace is now identified as a contact in the northeast limb of a large upright anticline. A thrust fault is present, however, on the face of Lion Mountain, a former center of mining activity. Movement on this fault brought Lodgepole-like limestone onto older marble, evidently from an outcrop much higher on Lion Mountain. The field relations can be interpreted either as a landslide contemporaneous with the intrusion of quartz-monzonite at Lion Mountain or as a large landslide older than the present drainage.

Thrust faults of several ages

Continuing study in the area of the early to middle Eocene Heart Mountain fault (loc. 7) by W. G. Pierce, H. J. Prostka, and W. H. Nelson places its age more precisely in the Absaroka Volcanic Supergroup. The newly identified Lamar River

Formation is partly older than the Heart Mountain fault, but the youngest of the Lamar River rocks apparently was deposited on the tectonically denuded area of the fault surface. Movement on the fault therefore occurred while the Lamar River Formation was being deposited. This time was one of more or less continuous volcanism.

R. G. Schmidt has mapped a thrust fault of unusual deformational style, the Shellrock Ridge thrust fault, in the Montana disturbed belt north of Helena (loc. 8). This fault connects southeastward with a major thrust previously mapped by M. E. McCallum in the Candle Mountain quadrangle. It has a strike length of at least 18 mi, a maximum stratigraphic throw of about 700 ft, and a probable minimum displacement of several miles. The Shellrock Ridge thrust cuts older thrust faults and folds, maintains a steep inclination along the strike, and (unlike the other large thrusts of this region) is not appreciably warped or folded. If the Shellrock Ridge thrust is younger than the folded Moors Mountain, Candle Mountain, and Eldorado thrusts to the west, it contradicts any general thesis that the major thrust faults in the Montana disturbed belt have developed progressively from east to west.

Mapping by B. A. Skipp shows that Silurian and Devonian rocks of both transitional and miogeosynclinal facies are present in a small window near Fish Creek Reservoir in south-central Idaho (loc. 9). The transitional facies, consisting of fossiliferous silty limestones of Silurian age (based on corals identified by W. A. Oliver, Jr., and brachiopods studied by J. T. Dutro, Jr.), is tentatively assigned to the Roberts Mountains Formation. This facies is thrust over the miogeosynclinal facies, as represented by the Laketown Dolomite (Silurian) and the Jefferson Formation (Devonian). Both of these facies are overridden by quartzite and conglomerate of the Copper Basin Formation (Carboniferous). Although the window itself occupies less than 3½ sq mi, the overlap of these facies within it suggests regional thrusting of at least several miles.

A major fault is inferred by S. S. Oriel in the southern Bannock Range (loc. 10), based on the absence of 10,000 to 15,000 ft of beds found by D. E. Trimble in a thick section of Precambrian metasedimentary rocks near Pocatello. At Oxford Mountain in the southern Bannock Range the basal part of the Pocatello section is overlain directly by uppermost Precambrian quartzite and argillite and by Cambrian limestone.

Strike-slip faulting in northern Idaho

The Hope fault, the northernmost of a series of northwest-trending strike-slip faults in the panhandle of northern Idaho, has about 16 mi of right-lateral offset near Pend Oreille Lake. Some 50 mi southeast (loc. 11), current mapping by A. B. Griggs shows that the Hope fault bends southward and can be traced at least another 25 mi. South of the bend, rocks of the Belt Supergroup (Precambrian) on the eastern side of the fault—a section 35,000 ft thick—form the nearly vertical limb of an overturned fold. To the north, this overturned limb changes into a normal anticlinal arch. North-trending faults, including a thrust fault, cut the fold, and the field relations indicate that the strike-slip movement, the folding, and the thrusting were synchronous.

Characteristics of the Cedar Ridge fault, Wyoming

Mapping along more than 28 km of the Cedar Ridge fault and its satellitic faults, in the Badwater Creek area, Wyoming, by R. E. Thaden indicates that the faults may have been the principal controls on the movement of possible uranium-bearing ground water. Dips on the Cedar Ridge fault, normally about 75° N., range from about 55° S. on southerly bends in the trend of the fault to about 50° N. on northerly bends. Just east of Dry Creek the fault appears not to make a sharp northerly excursion from its general trend as mapped heretofore but is overridden, and hidden, by a large detachment block of Wind River rocks which has slid subhorizontally northward across the fault. The block is about 2,150 m long and 950 m wide.

Hydrologic support of graben origin for the Snake River Plain

In spite of its size, the Snake River Plain of Idaho (loc. 21), which cuts across Basin and Range as well as Rocky Mountain structural features, constitutes one of the least understood geologic provinces in the United States. Hypotheses for its origin range from simple downwarping and filling with lava to spreading of the earth's crust and filling of the resulting rift with lava from the mantle. A synthesis of available geologic data, including recent hot-spring analyses by Robert Schoen, indicates that neither of these hypotheses adequately explains the data. The frequency of hot springs along the borders of the Snake River Plain implies that major border faults exist to provide deep permeability, a situation that negates the downwarp hypothesis. The spreading rift hypothesis is negated by the absence of tensional breaks oriented along the length of the eastern Snake River Plain as well as the absence of seismic events associated with the plain. Schoen concludes that the data best fit a hypothesis of origin of the Snake River Plain as a huge graben (a block downthrown along faults on two sides) filled concomitantly with downdropping by lava and sediments. This hypothesis of origin was first proposed in 1898 by Lindgren.

GEOLOGIC AND STRATIGRAPHIC STUDIES

Roof pendants in the Boulder batholith

H. W. Smedes has found remnants of two large roof pendants of deformed and thermally metamorphosed sedimentary rocks in the Boulder batholith northwest of Butte, Mont. (loc. 12), each covering about a square mile. One of the roof pendants is composed of at least 1,000 ft of upper

Paleozoic rocks (Amsden, Quadrant, and Phosphoria Formations); the other, of at least 600 ft of Mesozoic rocks (probably the Morrison and Colorado Formations). These remnants, together with numerous pendants that have been mapped before, are useful in reconstructing the eroded roof of the batholith. The pendants indicate that large areas in the western part of the batholith were emplaced beneath prevolcanic rocks, in contrast to the eastern part where the batholith intrudes the Elkhorn Mountains Volcanics.

Pleistocene lakes in Yellowstone National Park

The drainage basin of the Yellowstone River above the Upper Falls was repeatedly occupied by glacial and interglacial lakes, one of these being an interglacial lake that preceded the Bull Lake Glaciation (loc. 13). Studies by G. M. Richmond show that this lake was dammed by a plug of till in the ancestral canyon at the Lower Falls and that the lake level was at first 30 ft above the present level of Yellowstone Lake. The lake sediments locally contain pumice 180,000 yr old and a rhyolite flow 150,000 yr old. Another rhyolite, also about 150,000 yr old, flowed across a narrow place in the lake near LeHardys Rapids and formed a dam that raised the level of the southern part about 210 ft. The deposits that formed at this higher level are locally overlain by a rhyolite flow 125,000 yr old and by Bull Lake till. R. L. Christiansen has mapped the volcanic rocks, and J. D. Obradovich has measured their ages by the potassium-argon method. According to study of the pollen in two sections of the lake sediments by William Mullenders (Univ. Louvain), the flora was at times like that of today, at times representative of a cooler climate, and at times characterized by the presence of oak, birch, pine, hornbeam, beech, and hazel. The climate at the time this lake existed may thus have been periodically like that of the present hardwood forests of the eastern United States.

Metamorphic rocks in the Pioneer Mountains, Montana

Coarse porphyroblastic schists in large areas of the Wolsey Formation near Hecla (loc. 6) show multiple deformation and metamorphism, according to studies by E-an Zen. A pelitic assemblage is distinguished by biotite, andalusite, fibrolite, chlorite, plagioclase, quartz, muscovite, and tourmaline; a skarn assemblage is marked by grossularite, diopside, epidote, scapolite, quartz, and calcite. One pelitic rock contains unmistakable light-olive-brown glass in the spaces between metamorphic minerals, thus indicating that the rock was once partly molten.

Ordovician sedimentary rocks in central Idaho

The Bayhorse Dolomite (loc. 14), formerly assigned to the Cambrian(?), is very probably Lower Ordovician. The new assignment of age comes from collections of fossils of two kinds. The first, consisting of two small fragments of silicified brachiopods collected by S. W. Hobbs and W. H. Hays, has been studied by R. J. Ross, Jr. Although positive identification is prevented by a lack of hinge structures and cardinalia, the evenly ribbed nature of the ornamentation suggests an Ordovician rather than a Cambrian age. The second, consisting of several echinoderm columnals, has been examined by James Sprinkle (Univ. Texas, Austin) and by J. M. Berdan (USGS). They agree that this material suggests an Early Ordovician age. These collections were obtained by dissolving large samples of carbonate rocks. Repeated efforts over a period of 5 yr to obtain additional fossils by this method have not yet been successful.

A group of rocks—dolomite, quartzite, sandstone, shale, and conglomerate—between Precambrian sedimentary rocks and the Kinnikinic Quartzite (Ordovician) in east-central Idaho has long been considered Cambrian or Precambrian in age. Trilobites collected from these rocks in the Lemhi Range (loc. 15) by E. T. Ruppel and D. L. Schleicher and identified by R. J. Ross, Jr., indicate that the upper part of this group, at least, is of Early Ordovician age; the genera are characteristic of the Garden City Formation of Utah. These rocks are the only ones of this age known so far in east-central Idaho.

Dating of volcanic rocks near Pocatello

A hornblende andesite volcanic breccia in the Fort Hall Indian Reservation (loc. 16), provisionally correlated with the Absaroka Volcanic Supergroup by D. E. Trimble, has been determined to be between 40 and 47 m.y. old by R. L. Armstrong (Yale Univ.) using the potassium-argon method on samples of whole rock. A middle to late Eocene age is thus indicated, which is in accord with the time of Absaroka volcanism.

Eocene uplift west of the Teton Range

Additional evidence for the postulated Targhee uplift, an area now covered by rocks in the Snake River downwarp, has been found by J. D. Love. The uplift is believed to have been the source of exotic slide blocks of Precambrian quartzite, Paleozoic carbonate rocks, and Mesozoic conglomeratic sandstone, some as much as 150 ft across, that occur in an unnamed sequence of mafic volcanic rocks of middle Eocene age in the Teton Range (loc. 1). This sequence, which also includes lenses of gold-bearing quartzite boulder conglomerate, is at least 2,000 ft thick at the north end of the range, and isolated thin remnants of what is believed to be the same sequence occur high on the west flank of the Tetons about 8 mi northwest of Grand Teton Peak. The remnants on the west flank dip westward and truncate Paleozoic sedimentary rocks that also dip to the west, although less steeply. Thus, the underlying Paleozoic beds are believed to have dipped to the east when the volcanic sequence was being deposited. This inference, together with the presence of the exotic slide blocks that could have come only from western sources, suggests that

this part of the Teton Range was the eastern flank of the postulated Targhee uplift. The area of uplift subsequently sank, but the Teton Range rose and remained high.

IGNEOUS ROCKS

Volcanic rocks in central Idaho

D. H. McIntyre has divided the Challis Volcanics (lower Tertiary) near Challis (loc. 17) into two groups: (1) Rhyodacite lavas and olivine basalt from local vents that are related to basin-range faults and (2) tuffaceous rocks from probable cauldron sources north of the Challis area that fill basins of erosional and fault-block origin. The two groups partly intertongue, and they evidently began to accumulate after the start of basin-range faulting—the dominant structural mechanism in this region since the middle Eocene. The tuffaceous rocks include the Germer Tuffaceous Member of C. P. Ross, a unit consisting of bedded pumiceous and glassy plant-bearing deposits rich in biotite, hornblende, and quartz. They also include the Yankee Fork Rhyolite Member of Ross, a more complex unit of welded ash flows distinguished by assemblages of either quartz, sanidine, and plagioclase or by quartz and anorthoclase. The rocks known as the Germer enclose rhyodacitic lavas near Challis, and the ash flows known as the Yankee Fork occur both within the rhyodacite and near the top of the bedded biotite-bearing tuff.

Absaroka Primitive Area, Montana

Helmuth Wedow, Jr., and D. L. Gaskill have located the apparent source of the Slough Creek Tuff Member of the Mount Wallace Formation (H. W. Smedes and H. J. Prostka, 1972), namely a large dikelike body of intrusive tuff underlying Ash Mountain near Jardine, Mont. (loc. 18). This intrusive tuff is well exposed through a vertical height of 1,000 ft, and Ash Mountain is surrounded by broad exposures of the Slough Creek, locally over 800 ft thick. The two are much alike in texture and composition.

GEOPHYSICAL STUDIES

Paleomagnetism of Eocene rocks near Butte, Montana

The remanent magnetism of the Lowland Creek Volcanics (loc. 12) indicates two reversals of the geomagnetic pole during the early Eocene, 48 to 50 m.y. ago, according to measurements by H. W. Smedes and W. F. Hanna. Combined with stratigraphic and structural studies, these measurements further show that quartz latite ash flows collapsed chaotically into a graben west of Butte while still hot, thus forming a jumble of blocks that then cooled below the Curie temperature.

Gravity and heat flow at Marysville, Montana

The presence of a magma chamber that was filled with granitic liquid not more than 50,000 yr ago is implied by the coincidence of a 15 mgal negative gravity anomaly and a heat flow anomaly of 10 μcal cm^{-2} just west of Marysville, Mont. (loc. 20), according to studies by E. C. Robertson and F. E. Mazella (USGS) and D. D. Blackwell (Southern Methodist Univ.). The observed geothermal gradient of 100°C per kilometer of depth suggests that the top of this chamber is 3 km deep, assuming a diameter of 8 km, and that its present temperature is about 700°C. The gravity anomaly indicates a chamber measuring 5 by 10 km. Aeromagnetic data for the same area fails to show the presence of the magma chamber. This discovery provides an unusual opportunity to study the character of a magmatic body shortly after its intrusion.

Snake River Plain

Gravity and magnetic measurements and electrical resistivity soundings have been made along a section traversing the Snake River Plain from Arco to Blackfoot, Idaho (loc. 19), by D. R. Mabey, A. A. R. Zohdy, D. L. Peterson, and W. D. Stanley. The purpose of the work was twofold: (1) To determine the nature and configuration of the aquifer system that underlies the plain and (2) to determine the fundamental structure beneath the plain. Interpretation of the data suggests the following: (1) Basalt of the Snake River Group has a high resistivity (300–3,000 ohm-m) and a thickness that ranges from a few meters to approximately 2 km, (2) materials with relatively low to moderate resistivities—probably sedimentary and silicic volcanic rocks—underlie the basalt and have a total vertical extent ranging from 2 to 5 km, (3) depth to the pre-Tertiary basement is variable but is, in general, everywhere greater than 3 km, (4) the basement rocks are nonmagnetic and appear to be similar to pre-Tertiary sedimentary rocks exposed north and south of the plain, (5) a deep trough, where depth to basement exceeds 5 km, lies hidden beneath the present course of the Snake River, and (6) the earth's crust is apparently 5 km thinner beneath the plain than it is elsewhere in the region.

SOUTHERN ROCKY MOUNTAINS

MINERAL-RESOURCE STUDIES

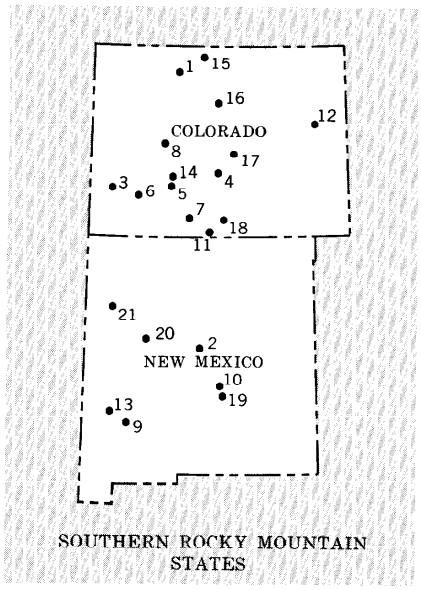
Fluorite in the Park Range, Colorado

Minor amounts of interstitial fluorite have been found by G. L. Snyder in the Mount Ethel pluton, a body of igneous rocks 1.4 b.y. old between Steamboat Springs and Walden, Colo. (loc. 1, index map). Fluorite vein deposits of Tertiary age in this pluton are being currently mined. The interstitial fluorite of the pluton is intimately intergrown with all the primary minerals and, though generally present only in trace amounts, can make up as much as 2 percent of the rock at

some outcrops. No fluorite has yet been found in the older Buffalo Pass pluton of this area (1.7 b.y.), even though this pluton is compositionally and texturally similar to the nearby pluton at Mount Ethel. The field relations suggest that some of the interstitial fluorite of the Mount Ethel pluton was redistributed by hydrothermal solutions during the Tertiary to form the economic vein deposits.

Iron smelting by the Spanish in colonial times

Slag near an arrastra in Priest Canyon, Torrence County, N. Mex. (loc. 2), suggests to D. A. Myers that the Spanish in colonial times were crushing and smelting iron ore. Fragments of quartzite in the slag and crushed pieces of hematite-bearing quartzite nearby are similar to rock found in a fault zone. Myers believes that the iron was used to repair the equipment of pack trains.



Coal in Disappointment Valley, Colorado

D. E. Ward has found persistent coal beds as thick as 30 in. along 3 mi of outcrop in the upper part of the Dakota Sandstone in Disappointment Valley (loc. 3). In the most favorable exposure, a coal-bearing section 8½ ft thick contains 6¼ ft of coal. Coal is currently strip-mined from the Dakota near Nucla, 25 mi northeast.

Rutile in the Wet Mountains

Rocks containing submarginal quantities of rutile, associated with less abundant monazite, have been mapped by Q. D. Singewald near Westcliffe, Colo. (loc. 4). The deposits are in lenses of white gneiss that contains variable amounts of sillimanite. These lenses are near a contact between garnet-bearing biotite gneiss and a thick unit of amphibolite and hornblende gneiss that locally contains vermiculite.

Resource information compiled for the Colorado River basin

L. S. Hilpert, in cooperation with Federal and State agencies, has compiled data on the quantity, quality, and extent of the principal mineral resources in the Colorado River basin. This compilation was done for the Pacific Southwest Interagency Committee, Water Resources Council, and is given in two administrative reports that deal separately with the upper and lower regions. The data are tabulated under known and predicted resources and are classified according to various types of geologic deposits. The compilation discusses mineral commodities by subregions.

Geologic details of Italian Mountain stock, Colorado, established

Mapping of the Italian Mountain stock, Gunnison County, Colo., by C. G. Cunningham, Jr., indicates an epizonal, composite intrusive body with spatially related lead-silver deposits. The stock is in a large, recumbent anticline along the Castle Creek fault zone and contains seven distinct rock phases, ranging from 60 to 72 weight-percent SiO_2. The contact aureole is in the hornblende hornfels metamorphic facies and affects mainly upper Paleozoic pelitic and carbonate sedimentary rocks. Gem-quality idocrase is found in the metamorphic aureole, and lapis lazuli is mined on a small scale.

IGNEOUS ROCKS

San Juan Mountains

Reconnaissance mapping by T. A. Steven and a gravity survey by Donald Plouff and L. C. Pakiser (p. B185–B192) has defined the Cochetopa Park caldera, a basin more than 16 km across in the north-central part of the San Juan volcanic field (loc. 5). The gravity profile shows an anomaly of 33 mgal, which can be explained by assuming an underlying body with a density 0.25 g/cm^3 less than that of the surrounding rock and shaped like a vertical cylinder 16 km in diameter, extending from the surface to a depth of 4 km. According to Steven, the caldera formed when a subsiding block sank as a trap door after eruption of the Nelson Mountain Tuff. The rocks along the southwest side bent downward toward the caldera, but no faults were formed. The other sides, however, are bounded by curving faults that form a fracture zone shaped like a horseshoe. The displacement on the east margin is estimated at 600 m. At the northwest, the caldera is filled with tuffaceous stream sediments, but the southern and eastern parts are filled with nonwelded pumiceous ash-flow deposits. These deposits are surmounted by a prominent

rhyolite lava dome that occupies much of the central part of the caldera depression.

R. G. Luedke and J. W. Hosterman have further confirmed the high-aluminous environment of the Red Mountain area in the western San Juan Mountains (loc. 6) by identifying additional alumina-bearing minerals in the chimney-type ore deposits. The presence of gibbsite and zunyite (a rare basic orthosilicate of aluminum) were verified by X-ray diffraction methods, both of these minerals being associated with sphalerite, galena, pyrite, quartz, pyrophyllite, and dickite within the ore bodies. Although gibbsite is ordinarily a weathering product, it is here undoubtedly of hydrothermal origin. The zunyite, together with quartz, is a dominant gangue mineral in two of the ore deposits.

Field study by P. W. Lipman in the southeastern San Juan Mountains (loc. 7) and radiometric dating by H. H. Mehnert indicate a long and complex history of igneous activity around the Platoro caldera after its collapse 29 to 30 m.y. ago during the late Oligocene. Successive lava flows around the caldera margin are dated at 29.1, between 27.8 and 26.7, 25.8, 22.8, and 20.2 m.y., and further sampling of the postcaldera lavas probably would disclose additional volcanic events. Isopach maps of ash-flow sheets that erupted from other calderas to the northwest between 28.2 and 26.5 m.y. ago show that the distribution and thickness of these sheets in the Platoro area was influenced by the growing constructional topography of the volcanoes near the caldera margin. With decreasing age, the general petrologic trend of the caldera-margin volcanoes was toward increasingly silicic types and from voluminous dark andesites to minor scattered lava domes of porphyritic rhyolite, these being contemporaneous with widespread flows of alkali-olivine basalt that occur nearby. The post-collapse igneous activity at the Platoro caldera thus spans a regional transition from predominantly andesitic volcanism to the eruption of bimodal basalt-rhyolite suites.

Laramide intrusives in Colorado

E. J. Young (1972) has compiled a map of the Laramide intrusive rocks in Colorado, which shows the locations of 486 chemically analyzed rocks, 125 dated samples, and 96 mining districts. The rocks are distributed along the well-known Colorado mineral belt and can be classified into groups of three ages: "Laramide" (50–80 m.y.), middle Tertiary (25–40 m.y.), and late Tertiary (8–12 m.y.). Laramide age dominates the northeastern and southwestern ends of the mineral belt whereas middle Tertiary age prevails in the middle part. Most of the mining districts are within 2 mi of the Laramide intrusives, and no important ore deposits are known to be related to the upper Tertiary intrusives. Molybdenum, which is associated with middle Tertiary intrusions, is the only metal correlative with any particular time episode.

West Elk Wilderness Area, Colorado

D. L. Gaskill (USGS), E. E. Larson (Univ. Colorado), and B. L. Bartleson (Western State Coll., Colo.) have identified a large composite intrusive in the West Elk Wilderness Area (loc. 8) as a major source of the overlying West Elk Breccia. The intrusive is exposed over an area of 20 sq mi and is locally altered and pyritized. Dikes that radiate from the intrusive were feeders for some of the breccia. One of the dikes cuts the Storm Ridge laccolith, thus indicating that the laccoliths of the West Elk Mountains are older than the West Elk Breccia.

Oligocene volcanism in Grant County, New Mexico

A sequence of volcanic rocks of Oligocene age and as much as 845 m thick has been defined by T. L. Finnell in the Twin Sisters quadrangle, New Mexico (loc. 9). These rocks lie unconformably on andesitic breccia of Late Cretaceous or early Tertiary age and on quartz monzonite of the Pinos Altos stock. The volcanic sequence includes welded ash-flow tuffs of quartz latitic and rhyolitic composition, flows of andesitic to basaltic composition, and intercalated tuffaceous sandstone and conglomerate. Olivine basalt flows that overlie the youngest of the rhyolitic ash flows cannot be assigned with certainty to the Oligocene and may be as young as Pliocene. These basalt flows are overlain unconformably by the Gila Formation of Pliocene and Pleistocene age.

Age of the Lincoln County laccolith

Biotite from monzonite sampled by Kenneth Segerstrom at a major laccolith in the Jicarilla Mountains, N. Mex. (loc. 10), has a potassium-argon age of 37.3±1.5 m.y., according to a determination by R. F. Marvin, H. H. Mehnert, and V. M. Merritt. Because this age differs widely from that of another intrusive in south-central New Mexico, the Bonito Lake stock (26.6±0.8 m.y.), the many intrusives of this region may represent more than one epoch of magmatic activity. Until now, all were considered to be early Miocene, but the age of this laccolith indicates activity during the early Oligocene.

Upper Cenozoic basalts

Basaltic volcanism, contemporaneous with extensional block faulting in the Rio Grande rift (loc. 11), extends across the southern Rocky Mountains to the Colorado Plateau on the west and to the High Plains on the east. This volcanism is characterized by basalt fields, by differentiated basaltic sequences, and by bimodal basalt-rhyolite associations, which together differ from the predominantly andesitic volcanism of the middle Cenozoic in this region, according to current studies by P. W. Lipman and C. M. Bunker (1972). The basalts range in age from 24 m.y. to only a few thousand years old. Although their compositions vary widely, the variations correlate more closely with geography than with age. The compositional ranges of these basalts are remarkably similar to those of many Pacific islands despite their contrast in geologic setting.

GEOPHYSICAL AND STRUCTURAL STUDIES

Young faulting in eastern Colorado

Evidence for major left-lateral faulting in Pliocene and Cretaceous deposits has been found in eastern Colorado by J. A. Sharps. The fault is expressed by a nearly continuous northeast-facing linear scarp, heavily masked by loess, that trends southeasterly for a distance of 80 mi across the central part of the Limon 2-degree quadrangle (loc. 12). Resistivity and gravity surveys by F. C. Frischknecht, L. Y. Allen, and D. M. Wilson across the scarp show marked differences that tend to confirm the existence of the fault. Linear features visible on aerial photographs suggest that the fault may extend an additional 10 mi to the southeast and 25 mi to the northwest. The scarp is 50 to 100 ft high and is believed to reflect differences in height of the Ogallala Formation (Pliocene) beneath the loess. Several ephemeral streams that cross the scarp show left-lateral offsets of their channels. Structure contours drawn from electric logs show that the Dakota Formation (Cretaceous) is locally higher on the northeast by as much as 75 ft although the Ogallala is higher on the southwest. This difference in apparent offset stems from the different directions of dip in these formations and is consistent with left-lateral displacement. Structure contours on the Dakota are offset left-laterally as much as 3 mi.

Gila Primitive Area and Wilderness

Geophysical maps of the Gila Wilderness (loc. 13) prepared by G. P. Eaton and D. L. Peterson show some striking correlations with geological and geochemical maps made by J. C. Ratté and D. L. Gaskill. The entire southwest edge of the wilderness coincides with an elongate positive gravity anomaly of 25 to 35 mgal. The anomaly extends northwestward from an extensively altered volcanic complex of pre-middle Miocene age on the south to the Mogollon mining district on the north. The anomaly probably reflects the presence of a linear batholith. Geochemical anomalies are found discontinuously along its entire length, and the axis of the anomaly is followed by scattered bodies of vent-zone rhyolites as well as by several conspicuous magnetic highs that are believed to mark individual plutons within the inferred batholith. Exposures of another altered volcanic complex on the east side of the wilderness coincide with a north-trending gravity high along the trend of the so-called Santa Rita–Hanover axis. This area, like the one to the west, is locally marked by prominent geochemical anomalies and by extensive rock alteration. These two linear gravity anomalies, if projected southward, would converge near Santa Rita, N. Mex.

PRECAMBRIAN ROCKS IN COLORADO

Cochetopa area

The Precambrian stratigraphic sequence of the Cochetopa area (loc. 14), which consists mainly of sedimentary rocks, has been shown by J. C. Olson to include also a section of volcanic rocks as much as 2 km thick, part of which was deposited under water. The volcanic rocks are rhyolitic and rhyodacitic flows, ash-flow tuff, and breccia, as well as tuffaceous sedimentary rocks and intermediate to mafic flows and pyroclastic rocks. These volcanic rocks are believed to be generally correlative with the Dubois Greenstone mapped by Olson and D. C. Hedlund in the Powderhorn area to the west. They are underlain by predominantly metasedimentary rocks at least 2 km thick, consisting of graywacke, siltstone, and sandstone and of rare conglomeratic beds interlayered with sills and flows ranging in composition from basalt to andesite. Metasedimentary rocks above the volcanic rocks are at least several kilometers thick and consist chiefly of fine-grained rocks such as siltstone and mudstone and fine-grained sandstone that have all been metamorphosed to quartz-biotite schist and locally to quartzofeldspathic schist. Layers of amphibolite and hornblende schist in this sequence are thought to be at least partly of metasedimentary origin.

Medicine Bow Mountains

M. E. McCallum has found that the Precambrian of the Kings Canyon quadrangle in the Medicine Bow Mountains (loc. 15) is largely granite that contains inclusions of sillimanite-grade metamorphosed sedimentary rock. The granite is locally foliated and appears to represent either a plutonic event of early Silver Plume age (about 1.42 b.y.) or an intrusion intermediate between the plutonism of Silver Plume and Boulder Creek Granites (about 1.65 b.y.). The granite in the northern part of the quadrangle is cut by a small stock of Sherman Granite (also about 1.42 b.y.), which is in turn cut by numerous faults and felsic dikes.

GEOLOGIC STUDIES

Magnetic anomalies near Ward, Colorado

An aeromagnetic high on Niwot Mountain (loc. 16), which was mapped by E. P. Smith in 1968, is attributed by D. J. Gable and J. T. Hemphill to the unusually high magnetite content (6–8 percent) of a unit of massive biotite gneiss. Another magnetic anomaly on nearby Mount Audubon, which was also mapped by Smith, coincides with an area of Tertiary monzonite rich in magnetite, apatite, and sphene. Although the monzonite outcrop is small, the aeromagnetic map suggests the presence of a much larger magnetite-rich body at depth.

Pleistocene landslides in the southern Front Range

Geologic mapping by G. R. Scott and R. B. Taylor near Canon City and Colorado Springs (loc. 17) indicates that catastrophic landslides have occurred in zones of brecciated and altered rocks along high-angle faults at the eastern

boundaries of the Wet Mountains and the Front Range. The larger slides cover as much as a square mile and reach nearly a mile in length. These masses apparently slid very rapidly, perhaps triggered by earthquakes. A large mass of rock that apparently fell suddenly from the east face of Cheyenne Mountain near Colorado Springs and that spread over an area of 3 sq mi contains boulders more than 20 ft in diameter. Judging from the ages assigned to movements on faults that displace physiographic surfaces along the mountain front, these landslides appear to be middle Pleistocene. Landslides of this magnitude in the future probably could be caused only by renewed movement on the faults. The present low seismicity of this region minimizes the possible dislodgement of slides by future earthquakes and makes their recurrence improbable.

Zeolitic alteration of Tertiary sandstones

Zeolitic alteration of arkosic sandstones has been found by J. D. Vine and E. B. Tourtelot in the Sangre de Cristo Formation of Pennsylvanian and Permian age near La Veta Pass and more widely in the Poison Canyon Formation of Cretaceous and Paleocene age and the Cuchara Formation of early Eocene age at the nearby Spanish Peaks (loc. 18). Laumontite, a calcium aluminum zeolite, is the principal alteration mineral and is known to form chiefly at the elevated temperatures associated with hydrothermal alteration or with burial metamorphism. The zeolitic alteration of this area is peculiar in that it has characteristics of both of these modes of alteration but is not typical of either. The arkosic sandstones probably were altered partly by an increase in temperature during the intrusion of igneous rocks, but the alteration is apparently dependent also on the movement of mineralizing fluids within the porous sandstones. The Paleozoic sandstones are altered close to a large stock of granitic felsite at Mount Mestas, and the Tertiary sandstones are more widely altered by the intrusion of the stocks of the Spanish Peaks and by their associated dike swarms that extend outward many miles. The zeolitic alteration is seemingly unrelated to either the numerous small copper-vanadium-uranium deposits in the Paleozoic sandstones or the local hydrothermal deposits in the igneous rocks. Instead, the alteration is confined to channel sandstones that are surrounded by mudstone. Thus, the main patterns of zeolitic alteration seem to be controlled by permeable conduits for mineralizing solutions through the sedimentary section.

Piedmont gravels along the White Mountains, New Mexico

Piedmont gravels as much as 50 ft thick cap mesas for distances of 8 to 10 mi east of the White Mountains, between tributaries of the Rio Hondo (loc. 19). Kenneth Segerstrom relates the surface below the gravel deposits to a once extensive surface along the eastern flank of the mountains which is characterized by deeply weathered bedrock now preserved only beneath the gravels on the ramplike interfluves. He correlates the piedmont gravels with the Ogallala Formation.

STRATIGRAPHIC STUDIES

Mesozoic unconformity near Acoma

An unconformity that cuts out all the Jurassic rocks between the Burro Canyon Formation (Lower Cretaceous) and the Chinle Formation (Upper Triassic) has been found by C. H. Maxwell near Acoma, N. Mex. (loc. 20). The Todilto Limestone (Upper Jurassic) pinches out in several miles when traced southward and is replaced by as much as 12 ft of conglomerate immediately below the Summerville Formation (Upper Jurassic). This conglomerate truncates an older unconformity between the Entrada Sandstone (Upper Jurassic) and the Chinle Formation. Farther south, the conglomerate is in turn cut out by the Cretaceous rocks. Erosion along the unconformity at the base of the Cretaceous cut deep enough to remove much of the lower half of the Chinle.

Wingate-Thoreau area, New Mexico

J. R. Best has determined the direction of transport of fluvial sediment in the Westwater Canyon Sandstone and Brushy Basin Shale Members of the Morrison Formation (Upper Jurassic) to have been generally east-southeast in the Wingate-Thoreau area (loc. 21). The Westwater Canyon is composed of multilayered units of sandstone separated by thin lenses of mudstone and siltstone, and the Brushy Basin is made up of sandstone lenses in claystone and siltstone. After deposition of the Brushy Basin, sedimentation was interrupted by broad upwarping of 40 to 60 ft, and erosion and weathering produced a surface of low relief covered by thin soil. The Dakota Sandstone was then deposited.

The Dakota Sandstone of this area shows several environments of deposition, according to Best. In ascending order, these are: (1) 40 to 50 ft of sandstone and carbonaceous shale that was deposited in a deltaic or fluviatile environment, (2) as much as 12 ft of light-gray shale and siltstone that was laid down in brackish water, (3) 20 ft of sandstone that accumulated at a shoreline, (4) 20 ft of sandstone, siltstone, and carbonaceous shale that again reflects deltaic conditions, and (5) 15 ft of sandstone that represents the return of the shoreline. Marine Mancos Shale overlies the Dakota.

In the western part of this area, most of the Morrison Formation has been removed by pre-Dakota erosion, according to mapping by M. W. Green, although the regional trend of erosion at the base of the Dakota resulted in the beveling of rocks in a southward direction. This local difference in the trend of regional erosion is attributed to events associated with development of the Gallup sag, a trough between the Zuni and Defiance uplifts.

Higher in the section at Gallup, Green and J. F. Robertson have found a previously undescribed bed of conglomeratic

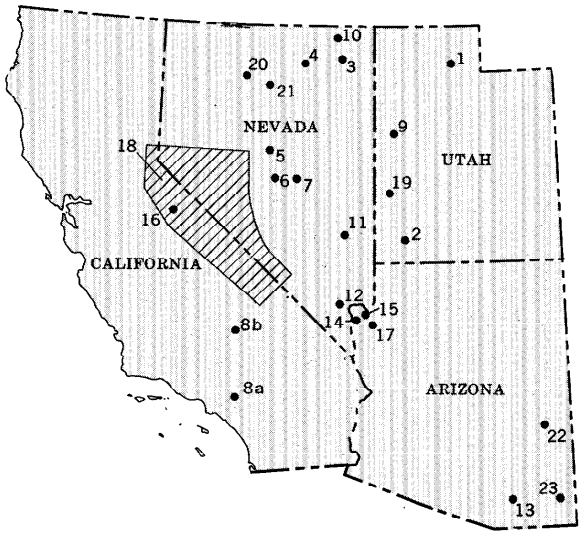
sandstone as much as 150 ft thick in the lower part of the Dilco Coal Member of the Crevasse Canyon Formation of Late Cretaceous age. The lithology and primary bedding structures of this sandstone suggest a continental-fluviatile origin as indicated by crossbedding, scour-and-fill structures, and lenticular beds of coaly carbonaceous shale. The contact with the marine Gallup Sandstone below is sharp, whereas the upward change to the upper part of the Dilco Coal Member is gradational.

BASIN AND RANGE REGION

STRATIGRAPHIC STUDIES

Pillow basalts aid in Precambrian correlation in Utah

Pillow basalts recognized by M. L. Sorensen in Precambrian rocks on the upper plate of the Willard thrust sheet in the Wasatch Mountains, near North Ogden, Utah (loc. 1, index map), intertongue with diamictites, which M. D. Crittenden, Jr., correlates with the Mineral Fork tillite in lower plate rocks. Crittenden and others (1972) have recently suggested regional correlations of stratigraphic sections in southern Canada, Idaho, Utah, and southern California, based on possible temporal equivalence of diamictites. In most of these sections, diamictites are closely associated with volcanic or volcanoclastic rocks. The pillow basalts in Utah are the first known from the Willard thrust sheet and reinforce both the lithologic comparison with other diamictite-bearing sections and the typical tectonic setting wherein thick basin sections are thrust eastward over thin autochthonous sections deposited on the shelf or craton.



STATES IN BASIN AND RANGE REGION

Tertiary stratigraphy update in the Iron Springs mining district, Utah

New mapping in the Iron Springs district in southwestern Utah (loc. 2) by P. D. Rowley, which amplifies the work of the late J. H. Mackin (1960) and correlates well with work by many others in adjacent areas, provides the following stratigraphic framework. The fluviolacustrine Eocene(?) Claron Formation, which forms the base of the Tertiary sequence, was derived in part from the Laramide thrusted Upper(?) Cretaceous Iron Springs Formation and older rocks. The contact between the Tertiary sequence and the underlying rocks is in part an angular unconformity. Ash-flow tuffs of the upper Tertiary Needles Range Formation subsequently were derived from unknown Great Basin sources to the west and spread north, northeast, and south of the Iron Springs area but were generally excluded from the district proper. The ash-flow tuffs of the lower Baldhills Member of Mackin (1960) of the Isom Formation (Eocene or Oligocene) were derived from vents in the southwestern Black Mountains and covered vast parts of southwestern Utah, including the Iron Springs district; the overlying ash-flow tuff, the Hole-in-the-Wall Member of the Isom Formation, perhaps derived from the same source, is confined to the Iron Springs region and areas to the south and west. As noted by P. L. Williams (unpub. data, 1972), regional ash-flow sheets of the Oligocene or Miocene Leach Canyon Tuff Member, overlying Bauers Tuff Member, and the Harmony Hills Tuff Member were erupted from Great Basin sources lying probably west of Iron Springs. These volcanic rocks spread over large parts of eastern Nevada and southwestern Utah and pinched out in the northern part of the Iron Springs district, the Black Mountains, and along the west edge of the High Plateaus against a growing highland of volcanic mudflow breccias and lesser lavas and ash-flow tuffs that make up the huge Marysvale volcanic pile. During and after pluton emplacement and the resultant iron mineralization, regional ash-flow tuffs, volcanic mudflow breccias, lavas, and gravity slide debris of the lower to middle Miocene Rencher and middle Miocene Page Range Formations were deposited; they pinch out northward in the district. The Tertiary history was closed with the deposition of coarse to fine clastic sediment and minor basalts. This period of volcanic activity overlapped the major period of block faulting in the Great Basin and the uplift of the nearby Colorado Plateau area.

Stratigraphic evidence for multiple thrust faults in Elko County, Nevada

The southern Snake Mountains north of Wells, Nev. (loc. 3), consist of a complex array of distinctly different stratigraphic sequences separated by thrust faults, according to R. A. Hope. The basal autochthonous sequence exposed along Bishop Creek, which is typical of these rocks in eastern Elko County, contains Devonian (Simonson and Guilmette) and Mississippian (unnamed limestone and Diamond Peak) rocks. North of

Finks Canyon, an allochthonous thrust sequence overlies the Bishop Creek sequence and consists of limestone bioherms, shale, sandstone, and cherty limestone which contain Devonian fossils near the base. North of this sequence, and apparently separated from it by a major fault, is a third sequence which contains Ordovician (Pogonip, Eureka Quartzite and Hanson Creek), Silurian (Roberts Mountain) and Devonian (unnamed limestone) formations. A fourth, allochthonous, siliceous, and detrital sequence of Ordovician (Valmy?) age overlies all three earlier sequences, and this sequence is in turn overlain in thrust contact by Permian rocks.

The thrust faults apparently had a predominantly eastward component of motion, but they may have moved at different periods of time. Some show evidence of latest Permian or Mesozoic movement, but there may have been earlier movement accompanying the Antler Disturbance (Early Mississippian). The magnitude of displacement is unknown but may have been large considering the varied lithologic units of comparable age that have been juxtaposed here.

Stratigraphy of Silurian and Devonian rocks, Cortez-Carlin gold area, Nevada

Gold ores now actively mined at Carlin and Cortez (loc. 4) occur as large disseminated deposits in limestones and calcareous shaly beds of the Silurian Roberts Mountains Formation. The stratigraphic section at the open pit mines includes the Late Ordovician Hanson Creek Formation which underlies the gold-bearing Silurian carbonate rocks. Overlying the Silurian is the Rabbit Hill Early Devonian (Helderbergian) succeeded upward by coral-rich Early and Middle Devonian strata of the Nevada Formation. All these beds are intensely faulted and are locally in thrust fault relationship to Ordovician graptolite-bearing beds of the Vinini Formation. Details of the stratigraphy have been partially worked out in the Cortez vicinity by detailed geologic mapping combined with studies of the rugose coral and brachiopod faunas by C. W. Merriam. Silurian and Devonian rocks of the Cortez-Carlin area are correlated paleontologically with similar units in the Antelope and Toquima Ranges to the south and with those of the Inyo Mountains in California.

Westernmost exposures of eastern assemblage lower Paleozoic rocks in Nevada

E. H. McKee's mapping in the Toiyabe Range south of Austin, Nev. (loc. 5), has disclosed two distinct sequences of rocks separated by the Roberts Mountain thrust fault. The lower plate sequence consists of Paleozoic carbonate rocks characteristic of the eastern assemblage, and the upper plate sequence of siliceous and volcanic rocks is characteristic of the western assemblages. These outcrops at about long. 117° represent the westernmost exposures of the lower Paleozoic eastern assemblage in Nevada.

Clarification of the stratigraphic and structural relations of the Diablo and Pablo Formations

R. C. Speed (USGS) and J. R. MacMillan (Northwestern Univ., Evanston, Ill.) have reinterpreted the Diablo and Pablo Formations of H. G. Ferguson and S. H. Cathcart (1954) in the vicinity of Jett and Wall Canyons (loc. 6), southern Toiyabe Range, Nev. The Diablo Formation in Jett Canyon consists of two units: a thin, fossiliferous calcareous unit and a much thicker terrigenous clastic unit. Sandy limestone and limy sandstone of the calcareous member overlie the Ordovician Palmetto Formation with angular unconformity and contain the fossils characteristic of the Permian Phosphoria fauna that were reported by Ferguson and Cathcart. The terrigenous clastic unit, consisting of sedimentary breccia, grit, and siltstone, is allochthonous with respect to the subjacent calcareous member and contains fossils only as clasts. Ferguson and Cathcart believed the two members were in depositional continuity and extended the Permian age assignment into the clastic unit. Although certain terrigenous clastic rocks elsewhere in the Toiyabe Range, assigned by Ferguson and Cathcart to the Diablo Formation, bear late Paleozoic fossils (F. J. Kleinhampl, oral commun., 1971), reconnaissance studies indicate that the Diablo Formation may comprise a number of different lithic units of highly varied tectonic history. Consequently, the terrigenous clastic unit of the Diablo Formation in Jett Canyon is currently undated because of the thrust contact between the two units at Jett Canyon, the lack of indigenous fauna in the clastic unit at Jett Canyon, and the uncertain relationships of the clastic unit at Jett Canyon with other terrigenous clastic rocks in the Toiyabe Range.

The Pablo Formation is now restricted to an assemblage of bedded chert, pillow lava, and slate that is a multiply deformed tectonite and excludes coarse and fine clastics that are not tectonites. The contact between the revised Pablo and Diablo Formations is a thrust fault on which the Pablo is the upper plate. The Permian age assigned to the Pablo Formation by Ferguson and Cathcart was based on depositional continuity with the Diablo Formation and is, therefore, invalid. No fossils have been found in the Pablo Formation, and radiometric dates are not yet available. Consequently, current age assignment is based on regional lithic and structural correlations. The Pablo is probably equivalent to multiply deformed chert, slate, and volcanic sedimentary rocks mapped as Excelsior Formation by Ferguson and Muller (1949) in the vicinity of Mina where they are demonstrably pre-late Late Jurassic. Correlation with rocks of moderately similar lithology and tectonic fabric 40 mi north in the New Pass Range, which have been correlated with the Pumpernickel Formation in the Sonoma Range quadrangle by J. R. MacMillan (1971), indicates that the Pablo is pre-late Early Triassic and, in general, late Paleozoic. If these correlations are correct, then the Pablo Formation is part of the extensive Golconda

Allochthon which was emplaced in western Nevada probably in middle Early Triassic time according to R. C. Speed (1971).

Possible outlier of Golconda thrust plate in the Monitor Range

F. J. Kleinhampl and J. I. Ziony report a sequence of strata about 1,000 ft thick in Danville Canyon, Monitor Range, Nye County, Nev. (loc. 7), consisting of chert, silicified locally calcareous mudstone, and minor siliceous siltstone and phosphatic grit that occur in the upper plate of a thrust fault overlying Paleozoic carbonate assemblage rocks. The upper plate strata strongly resemble some of the parautochthonous and allochthonous rocks to the west in the Toiyabe Range, some of which are known, and others inferred to be, of late Paleozoic age. In addition, an age similarity with some of the Toiyabe Range strata is indicated by the conodont *Gondolella* sp., a late Paleozoic to Triassic form, identified by J. W. Huddle, which is common to some strata in both areas.

A major allochthonous sequence of bedded chert, pillow lavas, and slate in the Toiyabe Range has a well-developed tectonitic fabric and is considered as possibly the southward extension of the upper plate of the Golconda thrust fault from north-central Nevada (R. C. Speed, 1971). This feature is a major early Mesozoic structure, comparable in extent to the mid-Paleozoic Roberts Mountains thrust fault, and Kleinhampl and Ziony conclude that at least some of the strata in Danville Canyon represent an outlier of the Mesozoic thrust near its easternmost limit.

In addition to the section described above at Danville Canyon, there is also a 2,000- to 3,000-foot undated unit consisting of black shale intercalated with dark-gray limestone and minor greenstone. This unit is tentatively correlated with a lithologically similar late Paleozoic sequence in the southern part of the Toiyabe Range which H. G. Ferguson and S. H. Cathcart (1954) mapped as autochthonous Permian Diablo Formation unconformably overlying older rocks but which locally at least includes strata of Pennsylvanian age. The structural relationships of these sequences are presently not clear, but an allochthonous or parautochthonous origin cannot be ruled out.

Extension of Cordilleran miogeosynclinal and eugeosynclinal strata into the Mojave Desert

Lower and Middle Cambrian miogeosynclinal strata have been recognized by F. G. Poole and J. H. Stewart north of Big Bear Lake in the San Bernardino Mountains and at Quartzite Mountain near Victorville, Calif. (loc. 8a). These strata are similar to the Wood Canyon Formation, Zabriskie Quartzite, and Carrara and Bonanza King Formations of the southwestern Great Basin. Cambrian and Ordovician eugeosynclinal strata have been recognized by F. G. Poole in the El Paso Mountains (loc. 8b) in eastern Kern County, Calif. These strata are also similar in lithology to correlative western facies rocks in central Nevada. The distribution pattern of lower Paleozoic geosynclinal facies in the Death Valley–Mojave Desert region indicates that the Cambrian and Ordovician strata in the El Paso Mountains are allochthonous. Poole postulates that these rocks were moved eastward on the Roberts Mountains thrust system in latest Devonian time and represent a remnant of the displaced eugeosyncline east of the zone of continental rifting that later obliquely truncated the Cordilleran geosyncline in southern California.

STRUCTURAL STUDIES

Gravity folds and flaps and thrust faults in western Utah

Mapping in the northern part of the Confusion Range of west-central Utah (loc. 9) has revealed a classic example of gravity-induced tight recumbent folds and thrust faults on the flanks of the Confusion Range structural trough. According to R. K. Hose, flaps developed in the folds are directed inward toward the axis of the trough; the upper plates of thrust faults, on the other hand, moved away from the axis of the trough; the relative thrust fault displacement is generally small (<1 mi).

These structural features, which are restricted to the upper Arcturus Formation and younger Paleozoic and Triassic strata, suggest that the rocks folded as they slid in toward the axis of the trough along incompetent gypsum zones in the Arcturus. Gravity apparently was the principal moving force for these local structures. The relative direction of movement of the upper plates is away from the trough axis and suggests tectonic tightening within the trough as a result of more far-reaching regional stress.

New estimate of the magnitude of Triassic overthrusting in north-central Nevada

An erosional window in Tertiary rocks in the Divide Peak area (loc. 10) mapped by R. R. Coats exposes two fossiliferous facies of Phosphoria age rocks separated by a thrust fault. Clastic rocks of the Edna Mountain Formation of Permian (Phosphoria) age and calcareous rocks of the Phosphoria Formation both unconformably overlie western assemblage siliceous and volcanic rocks of the Valmy Formation of Ordovician age. The Permian rocks were deposited on the western assemblage rocks following emplacement of the upper plate of the Devonian Roberts Mountains thrust fault.

The fossil faunas in the Permian facies studied by MacKenzie Gordon, Jr., differ significantly; their juxtaposition is attributed to major overthrusting from the west, probably during the early Triassic. The present maximum horizontal separation of the Edna Mountain Formation at Divide Peak, measured from the Antler Peak locality in Humboldt County, amounts to 96 mi.

Newly recognized calderas and stocks in southeastern Nevada

Reconnaissance geologic mapping of Tertiary volcanic rocks in Lincoln County, Nev. (loc. 11), by E. B. Ekren, P. P. Orkild,

K. A. Sargent, and G. L. Dixon has delineated two new caldera structures and two intrusive stocks. The center of a small resurged caldera, measuring 6½ mi in diameter, is centered on Bald Mountain in the Groom Range, 15 mi south-southwest of Tempiute, Nev. This caldera is the source of a sphene-bearing crystal-poor rhyolite welded tuff that tentatively has been traced 60 mi to the northwest.

A much larger caldera in the Delamar Mountains southwest of Caliente is nearly 15 mi in diameter and is the source of the widespread Hiko Tuff (Abraham Dolgoff, 1963; E. F. Cook, 1965). The Caliente caldera coincides in part with the "Caliente depression," considered by D. C. Noble and others (1967) to be the source area for welded tuffs such as the Hiko. Although other calderas may be present beneath voluminous rhyolite lavas southeast of Caliente, it is evident from the occurrence of Paleozoic and old Tertiary volcanic outcrops in the central and lower parts of the depression that this feature is due principally to denudation of a structural basin by the exterior-draining Meadow Valley and Clover Valley washes.

Granodiorite and granite stocks occur northwest of Caliente. The equigranular granodiorite body, located south of the Chief mining district about 3 mi north of Caliente, is approximately 1½ mi in diameter and has been moderately altered. A well-developed skarn zone in limestone and dolomite host rocks is exposed on the eastern flank. The granodiorite may be coextensive at depth with porphyritic diorite sills, plugs, and dikes that occur in and adjacent to the mines of the Chief mining district. The granite stock in Dry Lake Valley about 12 mi west-northwest of Pioche and west-southwest of Bline Mountain is mostly concealed by volcanic rock and alluvium. The body may connect with granitic rocks in the Bristol Range mapped by L. G. Westgate and Adolph Knopf (1932).

Crustal movements caused by mantle flow

The Frenchman Mountain structural block east of Las Vegas, Nev. (loc. 12), forms the western part of a narrow 60-mi-long, northeast-trending, highly deformed structural belt whose southeast boundary is a major left-lateral fault. Rocks of the Frenchman Mountain area have been shifted southwestward about 40 mi relative to the Sevier belt to the north and the Precambrian basement terrane to the south. The rock structures northeastward within this deformed belt reflect this sense of movement. R. E. Anderson believes that this extensive offset within a narrow belt (approx 9 mi) is best explained by transport on a fast-moving current of mantle material.

Complex thrust fault relationships in Tucson area

Geologic map analysis of the geologically complex region south and southeast of Tucson, Ariz. (loc. 13), by H. D. Drewes indicates that Laramide thrust faults involve minimum distances of tectonic transport toward the northeast on the order of 10 to 20 mi. The evidence for these thrusts consists of partial duplication of the stratigraphic sequence, largely of Paleozoic rocks, in two of three areally extensive thrust plates. The continuity of exposures in the thrust plates is good for a distance of 10 mi in the direction of transport and is fair across another 10 mi.

These thrust plates form an allochthonous carapace around the flanks of the Rincon dome whose core is a multiple lit-par-lit injection gneiss composed of at least three metamorphic formations of Precambrian age. Substantial thicknesses of core rocks overlie other thrust slices of Paleozoic rocks so that not all of the core is autochthonous. Rocks of both the core and carapace are overlain by deposits of mid-Tertiary and younger age, some of which slid off the rising gneiss dome as gravity fault plates and as megabreccia sheets.

Salt anticlinal structure in Detrital Valley, Arizona

The clay, silt, and limestone beds of the Muddy Creek Formation of Pliocene age enclosing a salt body have been upwarped into a south-plunging anticline that underlies Detrital Wash about 9 mi south of Lake Mead (loc. 14). The east flank of the anticline is outlined at the surface by a 3-mi-long arcuate cuesta that swings from a northeast strike at the south end to a northwest strike at the north end, according to R. L. Laney. Most of the west flank is concealed by alluvial deposits but, where exposed, appears to be complexly faulted. The salt body and the anticlinal structure are alined with a disturbed zone that extends 30 to 40 mi northward across Lake Mead into the Virgin Valley of Nevada where domal and anticlinal salt structures have been observed.

The anticlinal structure has been mapped by Laney, and core data from 10 test wells have been studied. The body trends north-northeast and is at least 3 mi long and 1.5 mi wide; the top of the salt is about 420 to 770 feet below the land surface. Four test wells bottomed in halite more than 900 ft below the land surface, but three test wells completely penetrated crystalline halite at depths of 1,182, 1,122, and 974 ft and bottomed in an interbedded halite, anhydrite, and clay unit 200 ft thick.

Massive Miocene gravity(?) faults in Arizona

Striations on the sole of an extensive gently west-dipping fault in the White Hills south of Lake Mead (loc. 15) and the regional, locally mixed distribution of Tertiary and Precambrian strata suggest that upper plate rocks slid east-northeastward over the Precambrian lower plate complex of the eastern White Hills. P. M. Blacet observes the sinuous, nearly north-south trace of the fault discontinuously for more than 20 mi. He tentatively interprets this feature to be the upturned toe of a major low-angle fault that developed in response to gravitational sliding off the east flank of the ancestral Black Mountains, 15 mi to the west. Similar, nearly contemporaneous low-angle westward-directed faulting in the Eldorado Mountains, south of Boulder City, Nev., has been described by R. E. Anderson (1971). Blacet suggests that

large-scale gravitational sliding occurred more or less symmetrically from both flanks of the north-northwest trending Black Mountains during late Miocene time.

Isotopic dating by E. H. McKee of a basaltic flow (10.6 m.y.) within the Muddy Creek Formation, which lies unconformably on the largely Miocene upper plate, provides both a confirmation date for mafic volcanism in the Muddy Creek Formation and a younger limit on the time of large-scale low-angle faulting in the White Hills. Late Miocene welded tuff (15.0 m.y.; K-Ar by E. H. McKee) occurs as tectonic blocks within the complex, locally chaotic upper plate, an occurrence placing the time of faulting within the interval 15 to 10.6 m.y.

Potassium-argon ages of volcanism and hydrothermal ore deposits at Bodie

Investigations of the potassium-argon geochronology of volcanic rocks and associated epithermal ore deposits by M. L. Silberman in the Bodie mining district, California (loc. 16), and preliminary data from comparable deposits at Goldfield and Tonopah, Nev., confirm a close temporal relation between emplacement of the volcanic host rock and metallization. The chronology established at the Bodie mining district began with andesitic host rock emplacement between 8.6 and 9.4 m.y. ago. Postore dacitic tuff breccias, lava flows, and small intrusive plugs are the local phase of an extensive suite of calc-alkaline volcanic rocks that erupted 7.8 and 9.5 m.y. ago in the Bodie Hills area. Adularia and other minerals from hydrothermally altered wallrock in the ore zone place alteration and mineralization between 8.6 and 7.1 m.y. (M. L. Silberman and C. W. Chesterman, 1972). One to two million years seems to be the lifetime of ore-depositing hydrothermal systems. Volcanism in the region ceased after ore deposition and did not resume until approximately 5 m.y. ago when rhyolite plugs intruded dacitic rocks west of the district.

GEOCHRONOLOGY STUDIES

Late Cretaceous plutonism and metallization south of Lake Mead

Late Cretaceous plutonism and mineralization are now recognized as an important element in the complex geologic history of the region south of Lake Mead, Ariz. (loc. 17). According to P. M. Blacet, three potassium-argon dates on hydrothermal and plutonic muscovite from the Gold Basin mining district document a close temporal relationship between mesothermal gold-quartz veins and spatially associated stocks of seriate-porphyritic quartz monzonite. Widespread vein mineralization and local greisenization are significantly younger than the granitoid intrusive rocks, but the ages indicate a complex plutonic and subsequent hydrothermal episode within a 5-m.y. interval near the end of the Cretaceous. A stock of similar, and presumably coeval, quartz monzonite porphyry is exposed in the Black Mountains 15 mi west of the Gold Basin district where it is also associated with gold-quartz veins, greisenization, and pervasive alteration.

GEOCHEMICAL STUDIES

Geochronologic compositional framework of volcanism in western Nevada and eastern California

Periodic Tertiary volcanic activity in western Nevada and eastern California (loc. 18) is characterized by chemically distinct rock assemblages. The oldest volcanic rocks are the rhyolite ash-flow sheets that were erupted between about 28 and 20 m.y. ago (E. H. McKee and others, 1971) from volcanoes in central Nevada, according to M. L. Silberman and E. H. McKee. From about 18 to 7 m.y. ago igneous activity is characterized by the eruption of local but voluminous fields of intermediate calc-alkaline volcanic rocks. These fields, typified by those at the Bodie Hills and Virginia Ranges, contain as much as 5,000 ft of volcanic rock and extend over areas on the order of hundreds of square miles. In places the calc-alkaline rocks are overlain by or intertongue with sedimentary rocks and airfall tuffs of the Siebert or Esmeralda Formations. Locally they are overlain by basaltic (generally alkali basalts or trachyandesites) and rhyolitic rocks.

Wallrock alteration in western Utah

Alteration of carbonate rocks of early Paleozoic age by Tertiary intrusives in the Wah Wah Mountains (loc. 19) is reported by L. F. Hintze (Brigham Young Univ., Provo, Utah). A complete, predominantly limestone Middle and Upper Cambrian sequence has been intruded by small diorite and rhyolite porphyry stocks. The limestones have been marbleized and locally skarn and breccia zones have formed. Pyrite disseminated around one of the stocks is oxidized into small limonite-hematite pockets; while too small to be of economic importance in themselves, they may indicate a mineralized leakage from below.

Potential exploration targets in the Edna Mountain area, Nevada

R. L. Erickson and S. P. Marsh (1971a,b,c,d) have devised a new series of maps that combine geochemical, geophysical, and geological data from their detailed studies of the northern one-half of the Edna Mountain 15-minute quadrangle (loc. 20). This area is of known minor metallization, but none of the deposits has been of economic significance since World War II when tungsten was mined from hot spring deposits. The numerous occurrences of mineralized ground combined with a broad varied spectrum of types of metallization, the localized intensely altered ground, structurally complex host rocks, an abundance of intermediate to silicic igneous intrusive rocks, and favorable aeromagnetic patterns suggest that this area may

conceal hitherto unrecognized buried mineral deposits and may warrant further physical exploration.

Two broad target areas are singled out. An intensely deformed block of siliceous clastic rocks of Ordovician age on the east flank of Edna Mountain contains highly anomalous amounts of mercury, arsenic, antimony, and tungsten. This metal suite is commonly associated with Carlin-type gold deposits. Although the gold content of these rocks is low, Erickson and Marsh believe that the Ordovician rocks moved into the area on the Roberts Mountain thrust fault, that the metal anomalies are leakage halos, and that more favorable host rocks may be present below the thrust plane. The mercury, arsenic, antimony, and tungsten may have been introduced relatively recently by hot-spring activity which overprinted earlier, more localized base-metal mineralization associated with Cretaceous granodiorite plutons.

A second broad target area is a belt of occurrences of anomalous amounts of base metals (copper, lead, zinc, silver) around the north flank of a Cretaceous granodiorite pluton. The pluton is very poorly exposed but is clearly reflected by a strong aeromagnetic high.

Genesis of the copper-bearing fluid at Copper Canyon

Recent drilling by Duval Corporation at Copper Canyon, Nev., in the Antler Peak quadrangle (loc. 21) reveals the laccolithic nature of an intrusion associated with nearby porphyry copper ore bodies whose origins are unknown. An attractive genetic hypothesis is that the copper ore bodies at Copper Canyon formed entirely from volatiles released from a water-saturated magma crystallizing under 1,500 m of cover. Furthermore, from studies of solubilities of water in granitic melts by others, magma at such depths is inferred to have contained at most 3 percent by weight dissolved water, of which about one-third must have been taken up by the crystallization of primary biotite, allowing 2 percent to be released to the country rock. Calculations by T. G. Theodore show that such a crystalline magma containing 38.2 percent by volume phenocrystic plagioclase in a 600-m-radius by 370-m-deep chamber could contain a maximum of about 5×10^9 kg magmatic water available for wallrock alteration and for potential metal transport. Published copper reserves included at least 1.7×10^8 kg copper at Copper Canyon. Accordingly, if all copper metallization here were assigned to fluids emanating from this body of rock during crystallization at depths of about 1,500 m, this would imply an unusually high copper solubility of about 33 gm/l (3.3×10^4 ppm) in those fluids. Such a solubility is about three times the maximum metal concentration estimated for the development of base-metal ores and about three orders of magnitude greater than minimum copper solubilities allowable by experiment for development of significant ore bodies. Such copper concentrations should also be reflected in the occurrence of copper minerals in the fluid inclusions, but such copper minerals are not present. Thus, although the approximate nature of the calculations is recognized as well as the constraints imposed by them, the hypothesis that fluids associated with metallization at Copper Canyon were derived entirely from the intrusive body is rejected; water sources other than those in the intrusion itself must be considered.

GEOPHYSICAL STUDIES

Ringlike feature on the Natanes Plateau

The geologic aspects of a ringlike feature 7 km across on the Natanes Plateau in southeastern Arizona (loc. 22), which is visible on an Apollo 9 infrared photograph, have been investigated by C. S. Bromfield and J. C. Ratté. The aeromagnetic properties and gravity of this feature have been surveyed by G. P. Eaton and D. L. Peterson. The feature is in a flat area where 600 m of volcanic rocks of Oligocene and perhaps older age rest on an irregular basement of Paleozoic sedimentary rocks and Precambrian granite. The central part of the feature is a downdropped area formed by 100 to 200 m of displacement on two faults that cross a broad horst. The horst, in turn, is bounded by northwest-trending Basin-and-Range faults. Deep erosion along these faults has created canyons that define the ring seen on the photograph. Moderate arching of the volcanic rocks within the ring is suggested by structure contours at the base of the youngest lava flows. The aeromagnetic survey shows a sharp 350-gamma positive anomaly centered within the ring, and this magnetic anomaly is enclosed by a subtle gravity low. The geophysical data thus suggest the presence of a small concealed silicic pluton, a circumstance in accord with the arching of the volcanic rocks and with the character of the arcuate faults.

Caldera in the Chiricahua Mountains

An aeromagnetic survey of the Chiricahua Mountains, Ariz. (loc. 23), was made by G. P. Eaton in support of geologic studies by H. D. Drewes in the Chiricahua Wilderness Area. The survey shows seven magnetic highs, with amplitudes ranging from 150 to 300 gammas, which are arranged along more than half of the circumference of the Turkey Creek caldera, a feature 13 mi across. The anomalies lie 1 to 3 mi within the topographic wall of the caldera, and most of them are associated with a unit of monzonite that is present in the moat of the caldera as well as in a central dome. A large centrally located magnetic low coincides with the Rhyolite Canyon Formation, and another low coincides with rhyolites in the moat on the north side of the caldera. When this magnetic survey is compared with geophysical maps that have been made for 16 other calderas in New Mexico and Colorado, the geophysical expression of these calderas is seen to be variable. Some calderas have pronounced magnetic expression, others have pronounced gravity expression, some have both magnetic and gravity expression, and others have no geophysical expression whatsoever. The value of geophysical

mapping in revealing the presence of a caldera in a given area is thus uncertain.

PACIFIC COAST REGION

CALIFORNIA

Continuity of the Coyote Creek fault, Borrego Valley, California

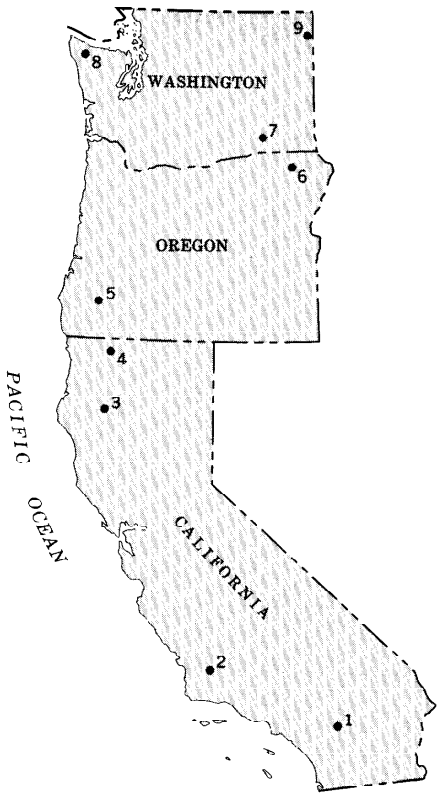
An area of possible convergence of major fault strands within the San Jacinto fault zone near Borrego Mountain, Calif. (loc. 1, index map), has been mapped in detail by R. V. Sharp. From Coyote Mountain where its trace is clearly delineated, the Coyote Creek fault extends southeastward nearly to San Felipe Creek. Branching strands of the fault there connect with the northernmost surface ruptures that formed during the 1958 Borrego Mountain earthquake. Mapping in the Borrego Badlands immediately east of this segment of the Coyote Creek fault has revealed no evidence supporting the convergence of the Clark fault (the strand of the San Jacinto zone that has the greatest total displacement in the Peninsular Ranges northwest of Borrego Valley) with the trace of the 1968 surface rupturing, as recently contended by M. J. Bartholomew (1970). The southeastward extension of the Clark fault in the Imperial Valley region probably lies several kilometers east of the Coyote Creek fault, but the precise location has not yet been identified.

Age, displacement, and continuity of the Rinconada fault

The Rinconada fault near Santa Margarita, Calif. (loc. 2), is a major northwest-trending high-angle fault. Southeastward, it is continuously traceable into the "Nacimiento" fault which in turn intersects the Big Pine fault in the San Rafael Mountains. Northwest of Santa Margarita, the Rinconada fault veers northward through Paso Robles and merges with faults known locally as the San Marcos and Espinosa faults. The latter is traceable northwestward to a point west of King City.

Detailed mapping by T. W. Dibblee, Jr., reveals that all these alined faults are parts of one major fault 250 km long, for which he proposes the name Rinconada fault. At its northwest end, the Rinconada fault is separated by a 3-km gap from the Reliz fault which is alined to the northwest. Both of these faults are nearly parallel to and about 34 km southwest of the San Andreas fault. Southeastward from Santa Margarita the Rinconada fault coincides with the southwest border of the Salinas block; northwestward it veers into this block.

The Rinconada fault was active both prior to and following deposition of the Pliocene-Pleistocene Paso Robles Formation. Drag folds indicate movement was mainly right lateral strike slip. Strata of Miocene and early Pliocene age are offset about 18 km; those of Late Cretaceous-early Tertiary age about 60 km.



PACIFIC COAST STATES

The block west of the Rinconada-Reliz fault zone, which presently forms the northern Santa Lucia Mountains, was pushed northward and severely deformed relative to the stable block on the east which includes the Salinas Valley. Deformation is progressively more intense southward in the east block.

Subdivision of southern Klamath Mountains

The western Paleozoic and Triassic belt in the southern Klamath Mountains (loc. 3) has been divided by W. P. Irwin (p. C103–C112) into three subdivisions that from west to east are named the Rattlesnake Creek, Hayfork, and North Fork terranes. The Rattlesnake Creek terrane is dominantly ophiolitic, includes appreciable soda granite, is structurally incompetent, and contains many deposits of chromite and manganiferous chert. The Hayfork terrane is largely andesitic volcanic rock, includes the syenodioritic Ironside Mountain batholith, is relatively competent, and contains lode-gold deposits. The North Fork terrane is also ophiolitic, but metalliferous deposits similar to those of the Rattlesnake Creek terrane appear to be nearly absent. All three terranes include lenses of Permian limestone, but the Rattlesnake Creek terrane also includes Triassic limestone. The lithologies making up the terranes suggest that the Rattlesnake Creek and North Fork terranes are slices of oceanic crust and that of the Hayfork terrane originated as an island arc.

Geosuture in the eastern Klamath Mountains

In the eastern Klamath Mountains (loc. 4), near Yreka and Fort Jones, Calif., P. E. Hotz has delineated a continuous, northeast-trending body of serpentinite lying between Ordovician-Silurian clastic rocks on the southeast and a belt of siliceous schists which contain blocks of glaucophane-lawsonite rock (blueschist metamorphic facies) on the northwest. The siliceous schists are overthrust northwestward onto a late Paleozoic-Triassic(?) greenstone-chert assemblage. Age of the upper-plate siliceous schists is unknown, but they are probably equivalent to the Stuart Fork Formation of G. A. Davis and P. W. Lipman (1962) which has been correlated with rocks equivalent to the greenstone-chert assemblage in the southern Klamath Mountains. The siliceous schist-blueschist terrane and serpentinite belt is regarded as a suture zone marking the site of collision between an oceanic plate of late Paleozoic-Triassic(?) age and a landward plate of early Paleozoic marine sedimentary rocks.

OREGON

Late Mesozoic tectonics in southwest Oregon

Work by D. L. Jones in the Days Creek–Riddle area in southwestern Oregon (loc. 5) shows that Upper Jurassic and Lower Cretaceous *Buchia*-bearing strata (Myrtle Group) were deposited on volcanic and ultramafic rocks that may represent oceanic crust and upper mantle. The Myrtle Group and underlying ophiolite structurally overlie the Dothan Formation, which is about the same age as the Myrtle Group. The contact between these coeval units is a major thrust fault that probably represents a northern continuation of the Coast Range thrust of the California Coast Ranges. The surface of the thrust fault has been deformed into a series of large overturned folds and has been dislocated by left lateral strike-slip faults.

The ophiolitic rocks in Oregon differ from analogous rocks in California in that they are metamorphosed to greenschist facies.

Contrasting compositions of "young" basalts of the Columbia River Group

Reconnaissance geologic mapping in Union and Wallowa Counties of northeast Oregon (loc. 6), by G. W. Walker (1972), has delineated a widespread key sedimentary horizon that separates an underlying thick sequence of flows and flow breccias, principally of Yakima-type chemistry, from an overlying unit of flows of mixed chemistry. The upper unit of flows, which represent a stratigraphically restricted part of the Columbia River Group, is of late Miocene or Pliocene age. Chemical analyses of flows from this upper unit indicate the first reported occurrence of late Yakima-type basalt in the region and the close stratigraphic association of Yakima-type with late Yakima-type flows, as well as andesite. The andesite is the most silicic flow rock yet found on the Columbia Plateau.

WASHINGTON AND IDAHO

Feeder dikes for Yakima Basalt in center of Columbia Plateau

During the course of studies on the Columbia River basalt, D. A. Swanson and T. L. Wright (Swanson and others, 1972) found feeder dikes for some of the youngest known flows of Yakima Basalt near the center of the Columbia Plateau east and northeast of Pasco, Wash. (loc. 7). Three dikes that cut the Pomona and Elephant Mountain flows are exposed in railroad cuts on the north side of Lake Sacajawea, 1.5 km east of Ice Harbor Dam. Two other dikes are exposed in a small borrow pit on the south side of the Columbia River, 2.8 km west of Ice Harbor Dam; one of these merges with the flow it fed, which is two or three flows above the Elephant Mountain flow. Basaltic pumice is locally interlayered between the young flows near the dikes. Poorly sorted, bedded sideromelane breccia 2 km west of Ice Harbor Dam is riddled with dikelets and has internal angular unconformities that suggest it is the eroded remnant of a tuff ring associated with the dikes. Three other dikes that cut a flow of probable post-Pomona age are exposed in a roadcut 3 km south of Eltopia, Wash., 25 km north-northwest of and along the projection of the dikes at Ice Harbor. All the dikes trend N15°W (±5°), are nearly vertical, and are less than 3 m wide. The three dikes east of Ice Harbor Dam contain large plagioclase and clinopyroxene clots, as does one of the youngest flows in the area. Flows and dikes can be correlated on the basis of petrography and chemistry. With the cooperation of Isidore Zietz, it was found that an elongate magnetic anomaly coincides with the known distribution of the dikes. Its amplitude, approximately 500 gammas, is large enough to suggest the presence of many unobserved dikes. D. P. Hill's seismic refraction measurements likewise suggest a major dike swarm.

Olympic Peninsula in the light of plate tectonics

Studies by W. M. Cady and R. W. Tabor during reconnaissance mapping in the Tertiary rocks on the Olympic Peninsula, Wash. (loc. 8), suggest that the basalts of the lower and middle Eocene Crescent Formation which form a westward opening horseshoe around the core of the Olympic Mountains are anomalous in the light of present tectonic theory. The pillow basalts and breccias of the Crescent Formation are typical oceanic tholeiites and have strong chemical affinity with oceanic ridge basalts. They appear to stratigraphically overlie and intertongue with graywacke and shale, but the bottom of this underlying sedimentary section is not seen for it is faulted against the complexly deformed Tertiary rocks of the Olympic core.

If the basalts originated along an oceanic ridge (a spreading center), plate tectonics theory would predict that they be underlain by ultramafic or other mantle derived rocks, not sediments. In fact, ultramafic rocks are essentially absent in the Olympics except for some small dikes of altered peridotite in the underlying shales and graywacke. Foraminifera from limestones interbedded in the crescent indicate shallow marine conditions in the late early to middle Eocene which is substantiated by subaerial columnar basalts on the east side of the horseshoe. If the volcanics were extruded from an oceanic spreading center, it must have been very close to the continental margin which supplied detritus for the underlying sediments.

Limits of Newport fault in northeastern Washington and northern Idaho extended

The Newport fault zone, which has been mapped and described where it occurs within the Newport 30-minute quadrangle (F. K. Miller, 1971) (loc. 9), was traced for about 7 mi north and about 40 mi east of the quadrangle by F. K. Miller. Beyond about 7 mi, the northward projection is uncertain because the fault becomes lost beneath thick glacial deposits. To the east, however, the fault lies about 1 mi north of, and roughly parallels, the Pend Oreille River for about 5 mi, at which point it turns northward and appears to follow the east side of the Priest River valley to the north end of Priest Lake. The trace of the fault has a U-shaped configuration; the west arm of the U extends up the Pend Oreille River valley, and the east arm extends up the Priest River valley. The U is about 25 mi wide and 25 mi long although the two ends of the fault undoubtedly continue farther.

It appears that all the low-grade Belt Supergroup rocks that lie between the Priest River valley and the Pend Oreille River valley are floored by this fault. The extensive terrane of plutonic and high-grade metamorphic rock that lies east of the fault in the Priest River valley and west of the fault in the Pend Oreille River valley may be continuous beneath the fault.

ALASKA

New scientific and economic findings of significance have resulted from many diverse field and topical investigations carried out in Alaska during the past year. Discussions of these findings are divided into six parts corresponding to six major regions. Locations of the regions and of the specific study areas are shown on the accompanying index map of Alaska.

NORTHERN ALASKA

Highlights of reconnaissance mapping in the northeastern Brooks Range

As a result of continuing work by W. P. Brosgé, J. T. Dutro, Jr., R. L. Detterman, and H. N. Reiser in the northeastern Brooks Range (loc. 1, index map), three new fossil horizons in the Neruokpuk Formation were discovered. It is evident that a large part of the rocks presently included in the Neruokpuk Formation represent early Paleozoic sediments. A graptolite identified as an *Orthograptus* by W. B. N. Berry (Univ. California, Berkeley) dates the gray phyllite and chert member of the Neruokpuk (Dutro and others, 1971, 1972) as Late Ordovician. Discovery of a brachiopod fauna identified by Dutro as Middle Devonian(?), possibly Early Devonian, in a previously unknown limy sandstone unit was particularly significant. This sandstone unconformably overlies the older chert phyllite member of the Neruokpuk and is itself truncated with strong angular unconformity by Mississippian sediments. A significant find was an ostracode fauna identified by J. M. Berdan as not younger than Devonian nor older than Silurian. The sequence of limestones and clastics from which these fossils came was previously unknown. They are believed to be younger than the chert phyllite member and may be a facies equivalent of the Middle Devonian(?) brachiopod-bearing beds.

The 1971 work also disclosed that the limy sandstone-siltstone unit, previously believed to be Devonian or Silurian (U.S. Geological Survey, 1971, p. A49), is Cambrian in age and overlies younger Cambrian rocks by fault rather than depositional contact. This unit has been designated as the calcareous siltstone and sandstone member.

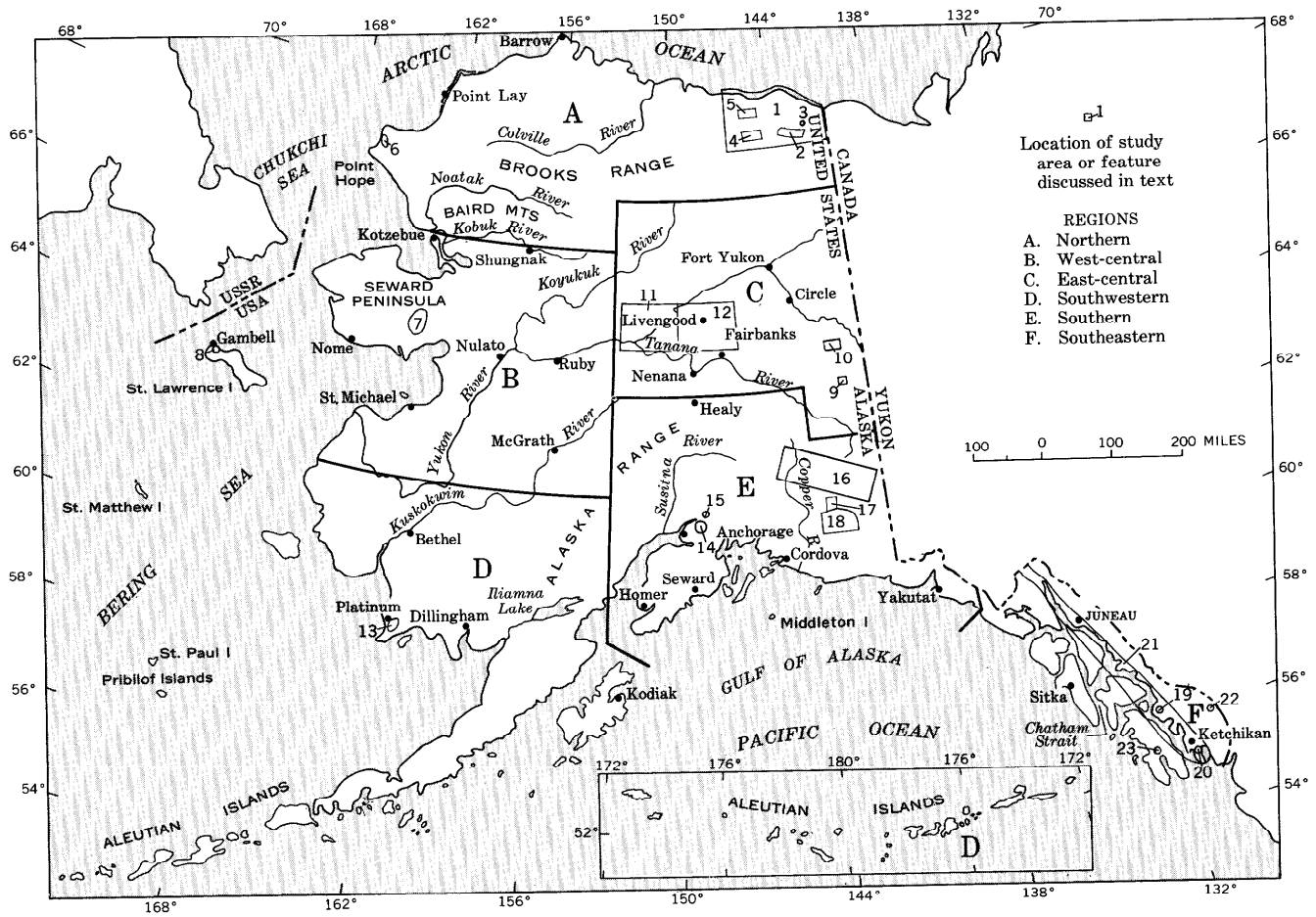
An ammonite found by Dutro and Detterman and identified by D. L. Jones as *Simbriskites* is the first evidence to date of the presence of Hauterivian-age sediments in northern Alaska. The fossil was found near the base of the thick Mesozoic sequence preserved in the structural basin of the Romanzof Mountains in the southern Demarcation Point quadrangle (loc. 2).

Analysis of samples taken by Detterman and Dutro from a 120-ft interval of iron- and manganese-rich sediments of Cretaceous age located in the prominent syncline in south-central Demarcation Point quadrangle (loc. 3) indicated manganese concentrations of 5 percent. Although presently not of commercial value, similar manganese-rich rocks in the basal(?) Cretaceous of the North Slope have wide occurrence and warrant consideration as potential ore.

Permian paleogeography of the Arctic

Distributions of Permian marine faunas, terrestrial vertebrates, and floras are explained in terms of the Permian geography of the Northern Hemisphere in a study recently completed by J. T. Dutro, Jr., and R. B. Saldukas. The Arctic Permian invertebrate fauna developed by isolation after the close of the early Permian. Relationships with the fauna of the Tethyan region can be explained by assumed paleocurrent patterns in the Permian seas. Post-Permian movements of continental plates are suggested by present-day positions of the fossil floras and faunas.

Distribution of lands and seas throughout the Arctic during the Permian resulted from earlier Paleozoic tectonic events. In



the Pacific region restricted marine connections with the Tethyan realm provided access for a limited number of warmer water animals, but the boreal faunal assemblages are generally distinct and relatively limited in number of genera.

Permian geography was dominated by three large land areas: Fennoscandia, central and southern Siberia (Angaraland), and Canada. Several smaller landmasses were present in China, the Seward-Chukotskiy region, northern and eastern Siberia, and north of present Alaska. Coal deposits and strata-bearing land plants covered a large area in central Siberia; saline basins with red beds developed in the Zechstein, Pechora, Perm, Canadian, and West Texas basins as the seas withdrew, generally in the later Permian. Eugeosynclinal troughs extended along the Pacific borders and apparently were limited to those regions. Volcanism accompanied deposition of predominantly clastic sediments in many parts of the eugeosynclines. Platform and miogeosynclinal deposits, dominated by carbonate rocks, preceded saline deposition in the basins and persisted on shallow shelves adjacent to the geosynclines.

Tectonic framework of northern and central Alaska

E. H. Lathram reports that, in the broadest and most simplified sense, the essential skeletal elements of the tectonic framework of northern and central Alaska consist of (1) a Precambrian and early Paleozoic Arctic (Innuitian) foldbelt in the Brooks Range and north (rather than a Precambrian Shield as earlier supposed), (2) a Precambrian and early Paleozoic "Cordilleran" foldbelt south of the Yukon River and along the front of the Alaska Range, (3) a late Paleozoic (Permian) and Mesozoic Yukon eugeosyncline between the older foldbelts and beneath the Bering Sea, with associated shelf sedimentation over the Brooks Range and north, (4) the western edge of the Yukon shelf, stable through Precambrian and Paleozoic time, and (5) the Seward Peninsula block, a stable shelf in Paleozoic time but the site of eugeosynclinal sedimentation and deformation in Precambrian time. Superimposed on these primary elements on land and on the continental shelf are Cretaceous and Tertiary basins containing the detritus of late Mesozoic, Laramide, and younger uplifts. The location and form of these basins are controlled by older structures which were reactivated. Observable tectonic elements have inherited their form and position from Paleozoic and possibly Precambrian time, and the history of their development shows a close relationship between them on space and time. Lathram concludes that Alaska is not formed of segments rifted from other continents and drifted to a final resting place. Instead, it is a continental mass formed by the accretion of foldbelts

resulting from interaction between the Canadian and Siberian Shields and the crust of ancient Arctic and Pacific Oceans during Precambrian and most of Paleozoic time and also between the resulting larger continental mass and the crust of an ancient Pacific Ocean (including Bering Sea) since late Paleozoic time. The dislocation of continental segments now seen in Alaska is only on the order of hundreds of miles or less and reflects internal adjustments along major transcurrent faults in response to the continued pressure of the expanding floors of these two oceans.

Carboniferous rocks of northeastern Alaska

Four sections of Lisburne Group (Carboniferous) were measured by A. K. Armstrong in the Franklin (loc. 4) and Romanzof Mountains (loc. 2) of northeastern Brooks Range, Alaska, on autochthonous but structurally complex terrane. The section on the west end of the Sadlerochit Mountains (loc. 5) is 1,500 ft thick and consists of Viséan (Chesterian) and Namurian (Morrowan-Atokan) Age carbonate rocks. The two sections in the Franklin Mountains are in excess of 2,400 ft thick and are Viséan (Meramecian, Chesterian) and Namurian (Morrowan-Atokan) Age. The Romanzof Mountains section is 2,800 ft thick and of similar age. Within these sections 10 foraminiferal assemblage zones are recognized and tied to the Cordilleran and Eurasian standards. A fauna of 14 taxa of lithostrotionoid corals are present in beds of Meramecian through Atokan age.

Lisburne Peninsula

Field checking on the Lisburne Peninsula by I. L. Tailleur added two important details to the growing knowledge of that complex region. An outcrop of Triassic rocks (Shublik Formation) was found within the Jurassic and Cretaceous terrane east of the Lisburne Hills (loc. 6). These outcrops, about 30 mi from the nearest exposures to the west, south, and east indicate the persistence of the Shublik Formation in the subsurface of the syntaxis between the De Long Mountains and the Lisburne Hills.

The age of the weakly metamorphosed unit of graywacke and mudstone along the west coast of the Lisburne Peninsula can now be provisionally considered as Paleozoic on the basis of new exposures which show a clear sedimentary contact between the wacke and the overlying Mississippian coal-bearing beds on the north side of Cape Dyer.

A potassium-argon age of 435±13 m.y., determined on mica from these rocks, also supports a Paleozoic age although a single Mesozoic(?) brachipod is unexplained.

WEST-CENTRAL ALASKA

Mapping of Seward Peninsula completed

Reconnaissance geologic mapping of the Seward Peninsula at 1:250,000 scale under the direction of C. L. Sainsbury was essentially completed in 1971, with several quadrangles at strategic locations mapped at 1:63,360 scale. Throughout the Seward Peninsula, metamorphic rocks of Precambrian age and carbonate rocks of Paleozoic age are intermixed by thrust faults in the Collier thrust belt. In the eastern Seward Peninsula, Precambrian rocks are thrust eastward over Jurassic-Cretaceous rocks, and glaucophane-bearing metavolcanic rocks of Jurassic-Cretaceous age are probably related to the thrusting. Elsewhere on the Seward Peninsula, glaucophane-bearing rocks are now known to include rocks of Precambrian age as well as metamorphosed mafic intrusive rocks which may be as young as Early Cretaceous.

Several distinct types and ages of intrusive granitic rocks are accompanied by different ores. Granites and quartz-monzonites of about 90 to 100 m.y. of age are accompanied by argentiferous base metal ore, whereas cassiterite deposits are localized near biotite granites about 74 m.y. old. Numerous fine-grained granites, not yet dated but believed to be of Late Cretaceous age, are unusually rich in thorium. Alkalic rocks on the eastern Seward Peninsula were not studied.

Alkaline dike swarm and ultramafic rocks in the Seward Peninsula

Geologic mapping in southeastern Seward Peninsula by T. P. Miller and D. H. Grybeck has disclosed a large alkaline dike swarm covering an area of 100 sq mi west of the Darby Mountains (loc. 7). The dikes consist of pulaskite, pseudoleucite porphyry, and foyaite and are potassium-rich. Most of the dikes are in a large Cretaceous pluton composed of granodiorite and quartz monzonite and have a consistent northeast strike. Dikes in the surrounding country rock of pre-Ordovician marble are parallel to regional structural trends. The dikes are part of a belt of strongly potassic and subsilicic rocks that extend for 180 mi on the Alaska mainland and may continue into Siberia.

A small ultramafic body, the first reported on the Seward Peninsula, was found by Miller and Grybeck east of the Darby Mountains in the southeastern part of the peninsula. The body is at least 2,000 ft long and is associated with strongly sheared diabase of probably Permian-Triassic age. It consists entirely of serpentinite, and analyses of composite grab samples showed 3,000 ppm nickel and chromium, similar to ultramafic bodies in interior Alaska. The sheared diabase associated with the ultramafic is part of a belt of similar rocks, commonly glaucophane-bearing, that extends for 60 mi in the eastern Seward Peninsula. The belt appears to be an extension of the ophiolite belt that bounds the Yukon-Koyukuk volcanogenic province to the east.

Discovery of ultramafic rocks on St. Lawrence Island

Onshore stream-sediment sampling and offshore bottom dredging suggest the presence of a buried ultramafic mass at Akeftapak Bay on the north coast of St. Lawrence Island (loc.

8). Stream-sediment samples collected by W. W. Patton, Jr., and Béla Csejtey, Jr., from the coastal plain bordering Akeftapak Bay have chromium concentrations as high as 5,000 ppm, and gravel samples dredged from the bottom about 2 km offshore by C. H. Nelson and D. M. Hopkins are composed of 75 percent or more of serpentinite pebbles. The ultramafic mass appears to be on strike with a belt of gabbro, diabase, basalt, and siliceous mudstone which can be traced in outcrop northwesterly across the island from Powooiliak Point on the south coast to the edge of the coastal plain bordering the north coast. The association of ultramafic rock with these mafic volcanic and intrusive rocks and with siliceous sediments suggests that the belt may represent a heretofore unrecognized ophiolite trend, possibly of major importance in the tectonic evaluation of the northern Bering Sea shelf.

EAST-CENTRAL ALASKA

Highlights of mapping in the Eagle quadrangle

An area with cold, bubbling springs and fairly extensive deposits of calcareous tufa was found by H. L. Foster on a tributary of Gold Creek in the Eagle A-4 quadrangle (loc. 9) during the course of geologic reconnaissance mapping in the Yukon-Tanana Upland. The springs emerge from a terrane of metamorphic rocks which include marble, quartzite, and quartz-mica schist and are near the contact, possibly a fault contact, of the metamorphic rocks with granitic rocks. Three analyses of the spring water indicate exceptionally high HCO_3 which cannot be explained by the marble alone. The source of the high HCO_3 is not known. Spectrographic analyses of sediment from the spring deposits contained 3 ppm silver, 7 ppm molybdenum, 700 ppm arsenic, and 50 ppm lead. In the valley below the springs the trees have all been killed, apparently from an unexplained episode of extensive glaciering of the stream valley.

An exceptionally fresh welded tuff deposit was recognized by Foster in the valley of Gold Creek, Eagle A-4 quadrangle. The deposit is about 5 mi long and up to ¾ mi wide and over 300 ft thick in one locality. The tuff could be as young as Pleistocene but may be Tertiary(?) like other welded tuffs in the Eagle quadrangle. The exceptionally fresh condition of biotite and the form and topographic expression of the deposit are suggestive of the younger age. No volcanic rocks younger than Tertiary are presently known in the Eagle quadrangle.

Reconnaissance mapping by Foster and F. R. Weber of the part of the Mount Sorenson ultramafic mass that crops out in the Eagle D-4 and D-5 quadrangles (loc. 10) indicates that it is the largest such body in the Eagle quadrangle. The body appears to have two limbs or branches, the northern one being the longest and extending more than 20 mi in an easterly direction to the vicinity of Alder Creek. The area of outcrop in the Eagle quadrangle is estimated to be about 16 sq mi. The ultramafic mass is faulted, highly serpentinized, and contains numerous tectonic inclusions of meta-diorite. Its relation to adjacent Paleozoic(?) greenstones and fairly fresh to considerably altered mafic igneous rocks is uncertain. Small patches of gray and green chert were mapped near the ultramafic along the Seventymile River.

Although some slip fiber asbestos and narrow veinlets of poor- to well-developed cross fiber asbestos were noted, no definite areas with possible commercially significant asbestos were found.

Tertiary rocks discovered along Tozitna River

Reconnaissance geologic mapping by R. M. Chapman and W. E. Yeend has demonstrated that Tertiary nonmarine rocks in the Tanana quadrangle (loc. 11) are more extensive than was previously reported. Additional exposures 20 mi west of Tanana were found in the northeasterly-trending belt of Tertiary rocks already known along the Yukon River. A second belt of lignite-bearing Tertiary clastic rocks was discovered north of the Yukon along the easterly-trending valley of Tozitna River. This discovery may have tectonic implications inasmuch as the other belts of Tertiary rocks in the Yukon River valley are thought to be associated with strike-slip fault trenches.

Revision of age of the Livengood chert

The discovery in 1971 of graptolites in a thick sequence of bedded chert by D. M. Triplehorn (Univ. Alaska), Claire Carter, and Michael Churkin, Jr., (USGS), and an additional collection from the same site later in the season by W. P. Brosgé, R. M. Chapman, and F. R. Weber provide new evidence for dating and correlating a chert formation that is widespread in the Livengood quadrangle (loc. 12). The graptolites occur in a thin shale bed within a thick sequence of bedded chert that is exposed in a large borrow pit about 8.5 mi west of Livengood and near Lost Creek along the proposed trans-Alaska pipeline road.

This chert is part of the Livengood Chert, and, as originally described by J. B. Mertie, Jr. (1937), the formation includes not only chert but also some limestone, more or less silicified, and argillaceous rocks. Mertie, with some reservations, assigned a Mississippian age to this formation on the basis of a small collection made in 1918 of shelly fossils from a limestone bed located about 9 mi west of Livengood. Although this collection resembled some others that were thought to be Mississippian, it lacked any fossils that are clearly diagnostic of Mississippian age.

More recently, R. M. Chapman, F. R. Weber, and Bond Taber (1971) have subdivided the Livengood Chert into two units: a lower unit that is predominantly chert and an upper unit that is chiefly limestone and dolomite, in part silicified. Furthermore, the age of these units was reinterpreted to be in the range of Ordovician to Devonian on the basis of structural and stratigraphic evidence, but up to now the age was not confirmed by any paleontological evidence.

Preliminary identifications by Carter of the newly found graptolites indicate an age of Middle Ordovician which corroborates the stratigraphic position of the part of the Livengood Chert based on recent field mapping. Work on a more precise age determination of the graptolites as well as a reevaluation of the original and new shelly fossil collections from the neighboring limestone is in progress and should result in a much better understanding of the stratigraphy of central Alaska.

SOUTHWESTERN ALASKA

Red Mountain ultramafic complex, Goodnews Bay

Regional geologic studies by A. L. Clark and D. H. Grybeck show that the Red Mountain ultramafic complex (loc. 13), the probable source area of the Goodnews Bay platinum placer deposits, is part of an ophiolite-appearing terrane. The ultramafic body is part of a thick sequence of cherts, pillow basalts, greenstones, diabase, and intercalated limestone and argillite believed to be an ophiolite sequence of probable Jurassic age. Detailed studies of the complex showed that the south margin is layered. The south border grades from dunite to peridotite to pyroxenite to hornblendite at the extreme southern margin. Analyses of bedrock samples collected from the ultramafic body show that anomalous concentrations of platinum metals do locally occur within the body. Although the body has long been regarded as the probable source, this study is the first documentation of platinum metals occurring within the body.

SOUTHERN ALASKA

Mapping of the western Chugach Mountains

The name McHugh Complex was introduced by S. H. B. Clark for a heterogeneous assemblage of weakly metamorphosed clastic and volcanic rocks that are well exposed along the northwest flank of the Chugach Mountains near Anchorage (loc. 14). The complex consists of two lithologically distinct but chaotically juxtaposed rock sequences with irregular outcrop patterns: a metaclastic sequence and a metavolcanic sequence. The metaclastic sequence, which makes up the bulk of the complex, was probably derived from a continental magmatic arc to the north and west. The metavolcanic sequence is thought to represent ocean floor accumulations that may have been tectonically mixed with the metaclastic sequence. The age of the complex is probably Late Jurassic and (or) Cretaceous.

The McHugh Complex is separated from Jurassic(?) and Cretaceous flysch deposits of the Valdez(?) Group by a low- to moderate-angle fault, which was named the Eagle River thrust fault. Another fault, which was named the Knik fault, juxtaposes the McHugh Complex and an older terrane of metamorphic and plutonic rocks to the north and west.

An ultramafic complex was discovered by Clark near the headwaters of Wolverine Creek (Anchorage C-5 quadrangle) about 15 mi east of Palmer, Alaska (loc. 15). The complex is part of the Chugach-Kenai-Kodiak ultramafic belt and is similar to the ultramafic complex near Eklutna.

The Wolverine ultramafic complex is a steep-sided, tabular, layered body about 5 mi long and ½ to 2 mi wide. It trends northeast, parallel to the major structures of the area. The complex is composed primarily of dunite, clinopyroxenite, and peridotite. Near the upper part of the complex light-colored, strongly altered gabbroic rocks form conspicuous layers. The lower part of the complex is in fault contact with amphibolite facies schists. Greenstone (metabasalt?), bedded chert, and altered diabase overlie the ultramafic complex. The sequence, which is typical of ophiolites, is interpreted as oceanic crust incorporated into the continent.

Ophiolite recognized on Resurrection Peninsula

A sequence of rocks near Seward, Alaska, mapped by G. C. Martin, B. L. Johnson, and U. S. Grant (1915) as "greenstones of Day Harbor and Resurrection Bay," were examined in shoreline outcrops by S. H. B. Clark, G. R. Winkler, and M. E. Yount as part of regional geologic investigations of the western Chugach Mountains. The rocks are interpreted to be a weakly metamorphosed ophiolite sequence of serpentinite and altered gabbroic rocks, diorite, diabase, massive basalt, and a thick section of pillow basalt which is overlain by greenschist facies metasedimentary and mafic metavolcanic rocks. The ophiolite and overlying metasedimentary and mafic metavolcanic rocks can be interpreted as the base upon which the thick Jurassic(?) and Cretaceous flysch of the Chugach-Kodiak-Kenai Mountains was deposited. These are the only known exposures of part of the base beneath the flysch deposits. The lower (eastern) contact is a fault that juxtaposes the ophiolite and the flysch. The upper (western) contact was not determined with certainty but appears to be gradational.

Age of blueschists near Seldovia

The age of an area of blueschist metamorphic rocks near Seldovia, Alaska, has been determined by R. B. Forbes and M. A. Lanphere. Potassium-argon ages of phengite from blueschist and actinolite and muscovite-chlorite concentrates from intercalated greenschist indicate that the mineral assemblages were developed approximately 190 m.y. ago. The blue amphibole, crossite, yielded a significantly younger potassium-argon age of 154 m.y. A similar pattern of mineral ages was obtained on blueschists from California. Results from the Seldovia area strengthen the interpretation that blue amphiboles do not retain radiogenic argon as well as phengite or actinolite. The Seldovia blueschist area which is associated with chert, mafic volcanic rocks, and serpentinites, may be a segment of a fossil subduction zone.

Cretaceous plutonism in the eastern Alaska Range

In the eastern Alaska Range (loc. 16) studies by D. H. Richter and M. A. Lanphere indicate that Cretaceous plutons on either side of the Denali fault were emplaced during relatively short but distinctly different time intervals, supporting the concept of major lateral displacement along the structure. South of the Denali fault two complex batholiths and several smaller intrusive bodies, all of granodiorite-quartz monzonite-quartz diorite composition, yield ages of 110 to 113 m.y. Compositionally similar intrusive rocks north of the fault yield ages of 92 to 93 m.y. Disseminated copper and copper-molybdenum deposits of economic significance appear to be associated only with the older Cretaceous plutons.

Geologic discoveries in the McCarthy C-7 quadrangle, Alaska

Significant results of the initial phase of mapping in the McCarthy C-7 quadrangle (loc. 17) include (1) finding outcrops of the upper member of the McCarthy Formation (Early Jurassic) and the Frederika Formation (Miocene) farther to the west than their previously known extents, (2) discovering an extensive welded tuff phase in the lower (Tertiary) part of the Wrangell Lava, (3) discovering extensive Tertiary intrusive rocks of intermediate compositions that penetrate the lower part of the Wrangell Lava, and (4) accumulating additional data on the complex Cretaceous stratigraphy of the Wrangell Mountains.

Mapping in the southwestern part of the McCarthy quadrangle (loc. 18) has delineated a narrow, steep fault that separates graywacke, slates, and argillites of the flyschlike late Mesozoic Valdez Group from the generally metamorphosed late Paleozoic rocks to the north. This fault, of regional tectonic significance, strikes northwestward across the southwestern part of the McCarthy quadrangle and extends into the contiguous Bering Glacier and Valdez quadrangles. It separates terranes characterized by distinctive geology and structure. South of the fault the widespread Valdez Group rocks are apparently characterized by steep northwest-striking structural features. North of the fault the dominant rocks are late Paleozoic volcanics, their volcaniclastic sedimentary derivatives, and gabbro. These rocks have been interpreted as oceanic crust and are believed to constitute the regional basement for much of southern Alaska south of the Denali fault (D. L. Jones and others, 1971). To the north the late Paleozoic sequence is unconformably overlain by, or thrust over, Mesozoic rocks that characterize large parts of the southern Wrangell Mountains. The structural style in this region is marked by numerous northwest-striking thrust faults that affect rocks as young as Early Cretaceous and are indicative of major crustal shortening. These structural features are significant in any regional tectonic synthesis and are generally in accord with plate tectonic implications.

SOUTHEASTERN ALASKA

Youngest Mesozoic bedded rocks in southeastern Alaska

Ammonites of Albian (latest Early Cretaceous) age, documenting the youngest strata known to date in southeastern Alaska, were collected on western Etolin Island (loc. 19), about 70 mi northwest of Ketchikan. The ammonites, tentatively identified by D. L. Jones as *Arcthoplites* and *Grantziceras*, were discovered by Jones, H. C. Berg, and R. L. Elliott during a 10-day reconnaissance of late Mesozoic stratigraphy and structure in the Alaskan panhandle. The fossils occur very sparsely in a 50-ft zone of thinly interbedded argillite and sandstone that intertongues with, and is intruded by, andesite. The ammonite-bearing beds conformably overlie *Buchia*-bearing strata and underlie thick deposits of andesitic tuff.

This discovery establishes that the youngest Mesozoic bedded rocks in southeastern Alaska are Albian, not Valanginian as thought previously from the *Buchia*-bearing strata. It is significant because (1) it improves the understanding of late Mesozoic events in the panhandle, (2) it narrows the possible age and duration of the Coast Range orogeny in southeastern Alaska, and (3) it provides a firm stratigraphic basis for comparing upper Mesozoic rocks in southeastern Alaska with less-deformed time-equivalent strata in nearby areas.

The Albian andesite correlates closely in age with several radiometrically dated (90–110 m.y.) zoned ultramafic complexes in southeastern Alaska. This near-contemporaneity supports the hypothesis that the andesitic volcanic rocks and ultramafics are genetically related, the ultramafics having fractionated in magma chambers feeding andesitic vents. Until now, andesitic volcanic rocks of appropriate age were unknown in southeastern Alaska, and the hypothesis, based mainly on petrologic and isotopic studies of the ultramafics, lacked supportive field evidence.

Geology of copper lodes on Gravina Island

An examination by H. C. Berg and A. L. Clark of copper lodes on southern Gravina Island (loc. 20) near Ketchikan, Alaska, showed that they probably are localized at or near the intersections of subhorizontal thrust faults and high-angle faults that postdate the thrusts. The lodes are mainly fissure veins and mineralized breccia zones in hydrothermally altered sedimentary, metamorphic, and intrusive country rocks that range in age from Silurian to Triassic. The age of the mineralization, based partly on the lack of deformation of the lodes and partly on regional structure, is inferred to be late Mesozoic or Tertiary.

The minerals include quartz, carbonate (ankerite? and dolomite), and barite accompanied by pyrite, hematite, chalcopyrite, and, locally, arsenopyrite and traces of bornite. Semiquantitative spectrographic analyses also reveal anomalous amounts of gold, silver, molybdenum, tungsten, and other metals. Calcareous country rocks near the lodes are intensely

dolomitized; noncalcareous host rocks generally are only slightly dolomitized but instead are locally silicified and enriched in ferric iron ("jasperized"). The lodes dip steeply, range from a foot or so to perhaps 10 ft wide, and have been followed by prospectors along strike for distances of as much as 600 ft. Chalcopyrite, pyrite, and hematite are sparsely disseminated in the country rocks between the main lodes, but to date this ground has been considered too low grade to warrant extensive prospecting or sampling.

The lodes, known since about 1900, were drilled in the 1950's and late 1960's by private interests and were mapped and sampled by the USBM in 1971. Estimates of ore grade and reserves are not yet available, but private drilling in the 1950's reportedly showed about 0.8 percent copper.

Plate tectonics in southeastern Alaska

A reconnaissance by H. C. Berg and D. L. Jones of upper Mesozoic stratigraphy and structure in the Wrangell-Revillagigedo belt (loc. 21) has led them to propose two new interpretations of southeastern Alaska's structural and tectonic history. One is that the upper Mesozoic rocks in the belt are remnants of a magmatic arc that can be traced almost continuously for more than 700 mi, from the eastern Alaska Range to (and possibly beyond) the southern tip of southeastern Alaska. The other interpretation holds that complex rock units actually comprise only four or five main tectonic elements that are either crustal plates, fragments of plates, or terranes formed by the interaction of plates. This interpretation supports the mobilistic hypotheses of J. W. H. Monger and C. A. Ross (1971) and D. L. Jones and others (p. B213–B219) of large-scale tectonic dislocation and continental fragmentation in southeastern Alaska.

Lamprophyre dikes in Ketchikan area

Hundreds of alined, tabular, northeast-trending, vertically dipping Tertiary lamprophyre dikes were recently discovered by J. G. Smith during mapping in the area of Hyder, Alaska (loc. 22). The full area intruded by the dikes is not yet known but is larger than 6,000 sq mi and extends into coastal British Columbia.

Most of the lamprophyre dikes occur in northeast-trending swarms a few miles wide which cut across the northwest structural trend of the coast range batholith and its metamorphic envelope. Field measurements show that over 60 percent have a strike that lies between N. 35° E. and N. 80° E. and dip within 10° of vertical. Many major linear topographic features such as fjords and major stream valleys also have this same northeast trend, and it is believed that differential erosion along the dike swarms and parallel joint sets, rather than faulting, is responsible for the northeast topographic grain.

Chemically, the lamprophyre dikes form an undifferentiated homogeneous group with alkali-olivine basalt composition (SiO_2 about 50 percent, total alkalis about 5.5 percent). Their chemistry closely resembles the Ketchikan volcanics (which they unconformably underlie) as well as nearby flows in British Columbia and on Prince of Wales and Dall Islands.

The structural setting and chemistry of the dikes suggest a mantle source and rapid intrusion without time for differentiation to occur.

Gravity field of southeastern Alaska

New gravity contour maps by D. F. Barnes of much of southeast Alaska suggest that the crust is thin in the western part of the archipelago but thickens rapidly towards the Canadian border. Most of the data for the maps were obtained by small-boat traverses which have now covered all the shorelines south and east of Chatham Strait. East of a line through Clarence Strait, Stephens Passage, and Lynn Canal, the gravity decreases in a steep gradient from positive Bouguer anomalies along these straits to anomalies below −100 mgals measured along the Canadian border. This gradient is believed to represent a crustal thickening of approximately 15 km. On the islands east of the gradient, the Bouguer anomalies range between 0 and +50 mgals and suggest a crustal thickness which is probably less than 20 km. Paleozoic rocks predominate over much of the region of thin crust, but some geologists have speculated that these older rocks may represent a detached continental fragment—a hypothesis that may be consistent with the gravity data. Local Bouguer anomaly highs are also associated with the large mafic intrusives which have been mapped along the western edge of the gravity gradient.

Southeastern Alaska—a displaced continental fragment

According to D. L. Jones, lower Paleozoic rocks of southeast Alaska are part of an anomalous continental fragment. Their presence substantiates evidence presented by J. W. H. Monger and C. A. Ross (1971) that a belt of upper Paleozoic rocks along the northern Pacific coast is detached from the main continental mass of North America. Silurian facies trends and other data seem to preclude lateral rifting as the main mode of detachment. Right-lateral transcurrent faulting seems more likely, and California seems to be the only suitable source for the anomalous fragment. Comparison of general lithologies supports the hypothesis that the Klamath Mountains and southeast Alaska are parts of a once continuous terrane that was dismembered during latest Paleozoic or early Mesozoic time.

Evidence for post-Devonian thrusting in Hydaburg area

Detailed mapping by G. D. Eberlein and Michael Churkin, Jr., in the vicinity of Hydaburg (loc. 23) has resulted in a much better understanding of the Paleozoic stratigraphy and structural development of this key area in southeastern Alaska. Previous work indicated a convergence of two lithologically

similar formations, the Descon Formation of Early Ordovician through Early Silurian age and the Port Refugio of Late Devonian age. New fossil collections were obtained and subtle stratigraphic differences were developed to distinguish the two formations. Their contact in the Hydaburg area is along a major thrust fault that has a minimum stratigraphic throw of 7,500 ft and a maximum throw of 13,500 ft. Rocks directly south and east of Hydaburg that were originally mapped as Devonian and thought to be correlative with the Port Refugio Formation are now known to be much older (Middle Ordovician) and part of the Descon Formation.

Field data obtained between Hydaburg and Hetta Inlet along Sukkwan Strait also suggest that the contact between the Descon Formation and the "Wales Group" is a fault, probably a thrust.

Orthogneisses of the Coast Range plutonic complex near Juneau

Mapping by D. A. Brew and A. B. Ford of the Juneau area schist belt has shown that, for a distance of about 40 mi, the western border of the Coast Range plutonic complex is markedly discordant on a regional scale to the pattern of Barrovian metamorphic isograds. In most small areas, this discordancy is not noticeable. However, one large sheetlike body of homogeneous, garnet-biotite-hornblende-quartz dioritic gneiss lies at high angle to the regional foliation pattern. Foliation within the body parallels external foliation and is at high angle to the contact with the schists. The body extends southeastward to merge with the crystalline terrane of the complex where relations indicating an orthogneiss origin are more obscure. Petrographic features pointing to an original magmatic origin of the gneiss include relict grains of early pyroxene and grains of clouded plagioclase with faint, euhedral oscillatory zoning. These features are strongly overprinted by effects of metamorphic recrystallization and of deformation. Close petrographic similarity between these rocks of demonstrable orthogneiss origin and the many granitic gneisses from the western border of the complex points to the possible importance of wide-scale magma production during a late stage of the Coast Range orogeny, before the terminal phase of regional metamorphism, as a precursor to the emplacement of the directionless plutons of the central belt that yield early Tertiary radiometric ages.

Nimbus IV camera experiment identifies Alaskan faults

On March 29, 1971, a rare cloud-free day in Alaska, the Image Dissector Camera System experiment on NASA meteorological satellite Nimbus IV obtained an exceptional image encompassing most of Alaska and part of western Canada (an area greater than 1,500,000 sq mi). Altitude of the satellite was 600 nautical miles, and ground resolution is about 2 nautical miles over most of the image. Snow cover was heavy and accentuated the contrast between uplands, which appear white because vegetation is nonexistent or too low to conceal the snow, and lowlands, which are dark because brush and trees have obscured the snow. According to E. H. Lathram (1971), lineaments that coincide with the position of most of the known or suspected major strike-slip faults in Alaska and westernmost Canada can be seen in the image. The Shakwak fault, commonly believed to connect the Denali fault system to the Chatham Strait fault by southward deflection, seems instead to continue to the southeast generally on strike with the western side of the Atlin horst in British Columbia. Also evident are the northern thrust front of the Brooks Range, the faults that bound the Sadlerochit and Shublik Mountains, arcuate fold and thrust structures in the Ogilvie and Mackenzie Mountains, and arcuate fold trends in the Chugach and Kenai Mountains. Northeast-trending lineaments cut across the Brooks Range, and short linears cut across the thrust belt of the Mackenzie Mountains, radiating outward from the Selwyn Mountains to the west. Other lineaments with unknown or limited information on structural control, coupled with those known to be structurally controlled, define a northeast-trending set of lineaments not apparent on most small-scale maps of Alaska. These lineaments are orthogonal to the known northwest-trending faults of the State; together they may represent a conjugate set of fractures in the crust—possibly the planetary set of "Megashears" noted by J. D. Moody and M. J. Hill (1956) and considered to have been formed in the lithosphere of a planetary body in response to changes in its rotational regime.

PUERTO RICO

Structural relations in south-central Puerto Rico

Mapping in the Ponce area by R. D. Krushensky has revealed that the central and southwestern structural blocks of Puerto Rico are separated by a zone of at least 10 major left lateral wrench faults, collectively known as the great southern Puerto Rico fault zone. The wrench faults cut both Cretaceous and Tertiary rocks. However, wrench faulting of the post middle Eocene plutonic rocks that intrude the Cretaceous sequence indicate that wrenching is post Eocene in age. Prior to wrenching the Eocene sequence had been moved into the area as a gravity slide plate. Gravity sliding of the Eocene sequence (Cuevas Limestone, Monserrate Formation, Anón Formation) can now be demonstrated in the Ponce quadrangle, the Jayuya quadrangle (P. H. Mattson, 1968) to the north and the Río Descalabrado quadrangle (Lynn Glover III, 1971) to the east. Gravity sliding of the Eocene sequence in the Adjuntas quadrangle is probable, but additional fieldwork will be necessary to demonstrate this.

Variation in metamorphism adjacent to San Lorenzo Batholith

J. W. M'Gonigle has shown recently that the contact between the San Lorenzo Batholith and intruded volcanic

rocks to the northeast is nearly everywhere at a high angle. Granodioritic rocks, however, underly one ridge of volcanic flows and tuffs northwest of the city of Humacao for a distance of about 1½ km, and the ridge thus represents a 150-m-thick roof pendant. Marble lenses intercalated in the ridge are locally altered to skarn deposits containing magnetite and hematite while the volcanics were locally changed to hornfels and hydrothermally altered.

By contrast, volcanic rocks southeast of Humacao have been altered to hornblende-mica schists along a gneissic border of the pluton. A high-angle fault is thought to separate the two areas of differing metamorphism, and the southern area may represent a somewhat deeper level of the intrusion.

Chronology of structural events in western Puerto Rico

New mapping by D. H. McIntyre in the Maricao quadrangle provides data for a chronology of structural events for western Puerto Rico:

1. Transcurrent faulting: post late Campanian–early Maestrichtian, pre-middle Eocene.
2. Major movement on west-northwest-striking left lateral wrench faults of the "Great southern Puerto Rico fault zone" plus folding: post-middle Eocene.
3. Emplacement of diorite and granodiorite plutons; hydrothermal alteration.
4. Left lateral movement of about 11 km on a west-trending wrench fault: pre-middle Oligocene.

Serpentinite relationships in the San Germán quadrangle

In the course of detailed mapping in the northern part of the San Germán quadrangle, southwestern Puerto Rico, R. P. Volckmann found that serpentinites exhibit an extremely complex relationship with tuffaceous volcanic rocks, limestones, and mudstones. Along the northern edge of the Guanajibo Valley the serpentinite appears to have been upthrown against the younger andesites along a series of subparallel, southdipping, high-angle reverse faults. Locally, however, small bodies of serpentinite have been intruded, diapirlike, into the andesites. One locality reveals a serpentinite breccia-conglomerate deposited on an erosion surface of fractured serpentinite. The conglomerate, which is about 60 ft thick, becomes finer grained near the top and grades sharply to a limy mudstone.

On the south side of the Guanajibo Valley, in the vicinity of San Germán, the serpentinite has been heavily intruded by dikes up to 15 ft thick which appear to be dioritic in composition. Blocks and wedges of volcanic material, some of which are tens of feet in diameter, are scattered throughout the serpentinite body. In two localities, rock fragments up to 10 in. in diameter, which appear to be fine-grained amphibolite, are incorporated within the fractured serpentinite. Inasmuch as the volcanic and amphibolite fragments are randomly oriented within the serpentinite and show no appreciable contact alteration, it is assumed they were incorporated and rafted during intrusion of the serpentinite in the cold state. The amphibolite fragments may represent the same unit which is exposed on the south side of La Sierra Bermeja, 8 mi south of San Germán.

Potassium feldspar in potassic and propylitic alteration

Study of drill core from 10 porphyry copper deposits and porphyry type mineral occurrences in Puerto Rico by D. P. Cox shows that potassium feldspar is formed not only during potassic alteration but also during propylitic alteration as a byproduct of the transformation of biotite to chlorite. Veinlets containing quartz, chlorite, potassium feldspar, epidote, and sulfides cut across areas showing intense biotitic alteration in the mineralized porphyries. Potassium feldspar was previously thought to occur only as a stable relict mineral in the propylitic facies of hydrothermal alteration.

GEOLOGIC MAPS

Much of the work of the USGS consists of mapping the geology of specific areas, mostly for publication as quadrangle maps at scales of 1:24,000, 1:62,500, and 1:250,000. Mapping the geology of the United States is a mandate of the Organic Act establishing the Geological Survey; the completion of geologic maps of the country at scales that will fulfill foreseeable needs and uses is a long-range goal.

The systematic description and mapping of rock units to show local and regional relations serve a major scientific objective, but most maps also serve more specific purposes as well. Some of the studies are for the purpose of extending geologic knowledge in areas of known economic interest; some are to gain detailed knowledge for engineering planning or construction. Still other mapping studies are carried on with the primary objective of providing solutions to problems in paleontology, sedimentary petrology, or a wide variety of other specialized topics.

LARGE-SCALE GEOLOGIC MAPS

Large-scale geologic mapping, principally at scales of 1:24,000 and 1:62,500, constitutes almost four-fifths of the geologic-mapping program of the USGS. Such large-scale maps are available for about a quarter of the conterminous United States. Approximately half of these maps have been produced by the USGS; most of the remaining maps have been produced by various State organizations and by educational institutions.

The USGS is carrying out large-scale geologic mapping projects in many parts of the country, with extensive cooperative programs underway in Connecticut, Kentucky, Massachusetts, and Puerto Rico. Other areas where mapping is underway include the Pacific Northwest, California, Delaware, Maine, Maryland, Michigan, Nevada, New Hampshire, Ohio,

Pennsylvania, Tennessee, Texas, Virginia, Wisconsin, and the Rocky Mountain States.

Large-scale geologic maps play a vital role in furthering scientific knowledge of the earth and also have many applied uses. Maps of mineralized areas not only help determine the scientific principles that govern formation and distribution of ore deposits but also are used as the basis for exploration for economic mineral deposits and for the preparation of reserve and resource estimates.

Many geologic maps are prepared in search for a better understanding of the processes and mechanisms that affect the earth's crust. Uses of these maps are growing in number and importance in the field of planning for more logical land use and for such large-scale engineering works as damsites, highway alinements, and subway routes. Actual construction is aided through location of vital construction materials and by providing the basis for site-preparation cost estimates. Another extremely valuable use of geologic maps is as an aid to avoiding hazards such as landslides, swelling clays, and those areas possibly subject to extensive damage during floods and earthquakes.

INTERMEDIATE-SCALE GEOLOGIC MAPS

Geologic mapping at a scale of 1:250,000 makes up an increasingly important part of the USGS geologic investigations program. The 1:250,000 and smaller-scale geologic maps generally are compiled from available large-scale geologic maps and supplemented by reconnaissance geologic mapping at intermediate scales. Mapping at 1:250,000 has now expanded to a point where it constitutes more than one-fifth of the geologic mapping program of the USGS. Many State geological surveys also have 1:250,000-scale geologic mapping programs which are underway or completed. These efforts by the Federal and State surveys as a nationwide program promise to provide geologic-map coverage of two-thirds of the United States by 1985; at the present time nearly 40 percent is covered. Figures 2 and 3 show the areas of the United States for which 1:250,000-scale geologic maps have been published.

The USGS is participating in mapping programs that will provide 1:250,000-scale geologic maps of most or all of Alaska, Colorado, and Nebraska within a few years. Single-sheet 1° by 2° geologic maps have been started in parts of Arizona, Idaho, Montana, New Mexico, North Carolina, Oregon, South Carolina, Virginia, Washington, and Wyoming.

Intermediate-scale geologic maps have a variety of uses. They help define areas where the need for larger scale maps is most critical, and they direct attention to broad geologic problems involving large segments of the earth's crust. They have proved ideal for geologic analysis of major tectonic and stratigraphic problems, for analysis of mineral provinces, and for relating broad geophysical anomalies to surface geology. A significant use for maps at intermediate scales, though still largely potential at this time, is as a basis for a systematic inventory of land uses and resources throughout the Nation.

MAPS OF LARGE REGIONS

Several maps of individual States or of all or large parts of the United States currently are in preparation. These maps, at scales ranging from 1:500,000 to 1:10,000,000, present reviews of various geologic features of the Nation in forms that show overall characteristics of the features in detail commensurate with the scales. Most are intended both as wall maps for contemplative reviewing and as working maps for further specific studies.

Geologic map of the United States exclusive of Alaska and Hawaii, scale 1:2,500,000, recompilation by P. B. King assisted by H. M. Beikman.

The new geologic map of the conterminous United States, scale 1:2,500,000, now compiled, will supersede the existing version of 1933 and will illustrate the vast increases in knowledge of the areal geology of the United States that have been obtained since that date. The new knowledge permits a better unification of rock units and hence a simplification of the legend as compared with the previous version. This will be based on extensive new map data, on improved stratigraphic correlations, and on radiometric data on volcanic, plutonic, and Precambrian rocks. A notable improvement will be a new classification of the Precambrian and nationwide Precambrian correlations.

Metallogenic map of North America, scale 1:5,000,000, P. W. Guild, compiler.

This map is a contribution to the Metallogenic Map of the World, sponsored by the Commission for the Geological Map of the World of the International Geological Congress and the International Union of Geological Sciences. The map is being prepared in cooperation with the Geological Survey of Canada, the Institute of Geology, University of Mexico, the Geological Survey of Greenland, and the Instituto Centro Americano de Investigación y Technología Industrial. This map will show major known deposits of metal-bearing and nonmetallic minerals, and their geologic-tectonic settings. A coproduct of the map compilation will be computer storage of data on deposits to facilitate rapid retrieval.

Geologic map of Arkansas, scale 1:500,000, revision by B. R. Haley and E. E. Glick of the USGS and W. V. Bush, B. F. Clardy, C. G. Stone, and M. B. Woodward of the Arkansas Geological Commission.

This revision of the State geologic map, begun in 1968 as a cooperative project, is about 80 percent completed. The map is being revised on the basis of published and unpublished reports and reconnaissance mapping.

Geologic map of Oregon, scale 1:500,000, G. W. Walker, compiler.

Compilation of the eastern part of the State is nearing completion; a map of the western part of the State was previously published (F. G. Wells and D. L. Peck, 1961). The present compilation, showing more than 50 geologic

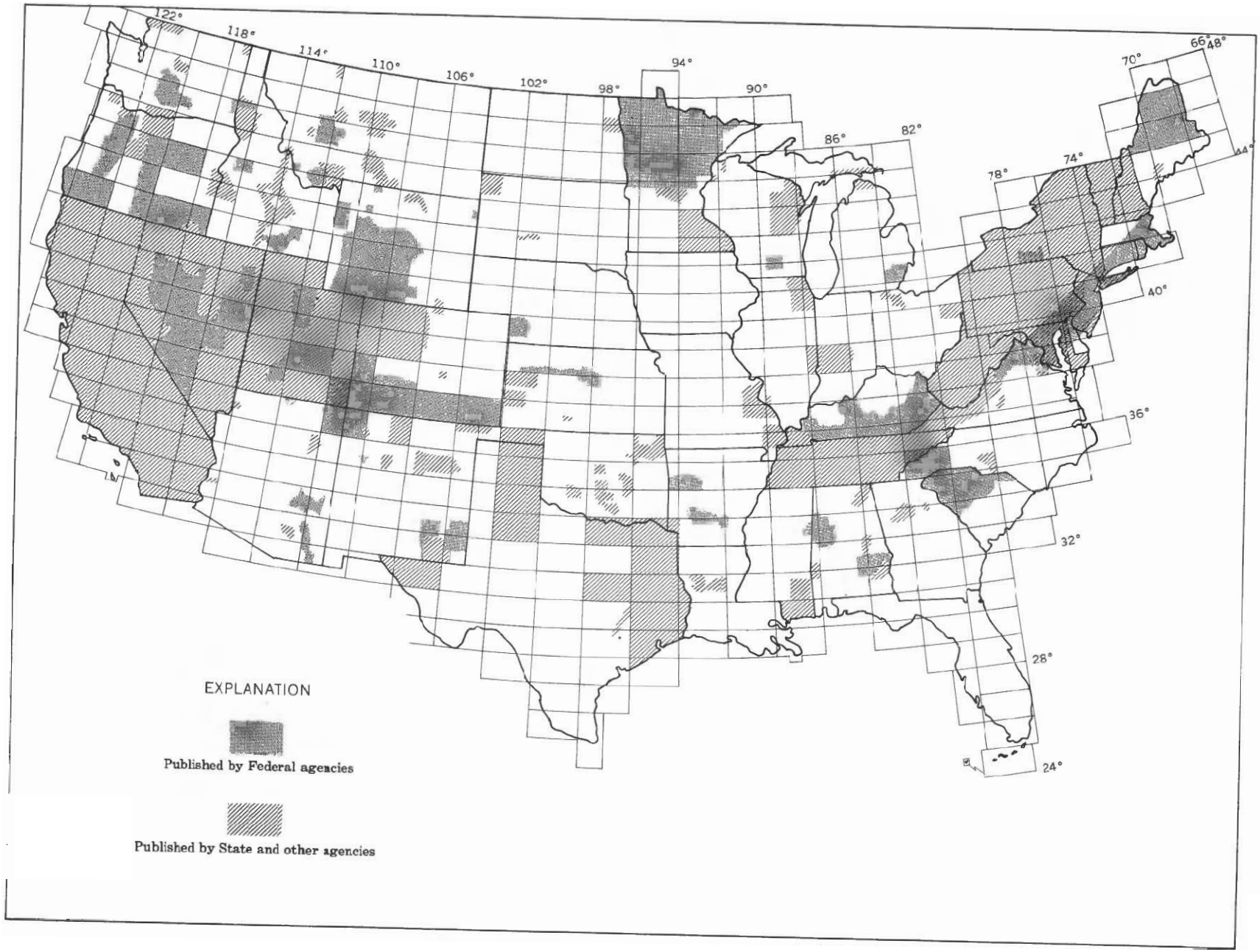


Figure 2.—Index map of the conterminous United States, showing 1:250,000-scale geologic maps published

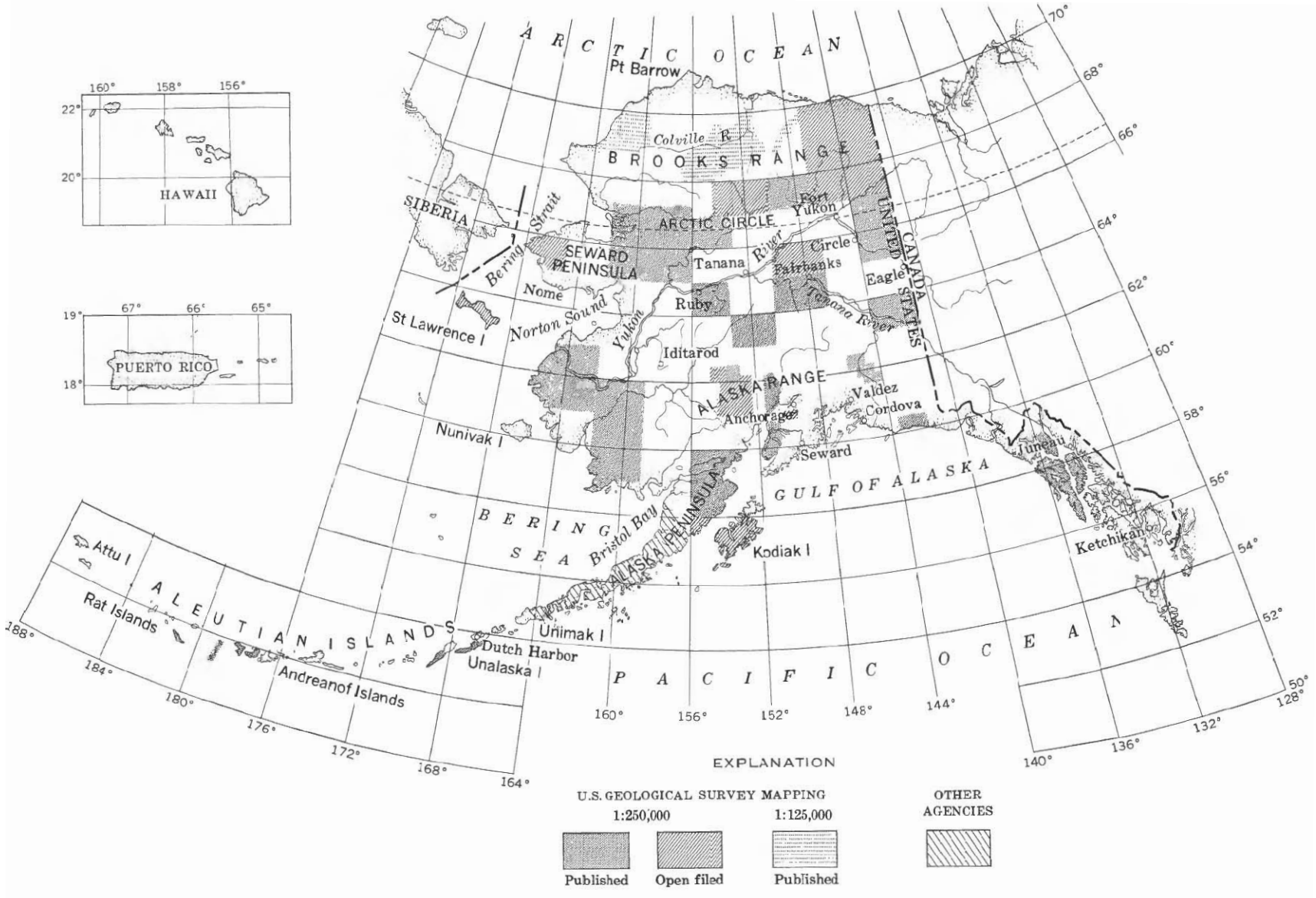


Figure 3.—Index map of Alaska, Hawaii, and Puerto Rico, showing geologic maps published or on open file as of June 30, 1972.

units, is based partly on available published and unpublished maps and partly on extensive new reconnaissance and photogeologic mapping. An inset tectonic map, scale 1:2,000,000, shows distribution of fold axes, major surface faults, and the position of postulated calderas and deeply buried faults.

Analysis of the Mississippian System, by L. C. Craig and others.

The analysis will include various maps at scales of 1:5,000,000 and 1:10,000,000 showing the standard information on structural elements and rock distribution during Mississippian time, and also special information maps.

Analysis of the Pennsylvanian System, by E. D. McKee and others.

The analysis will include various maps at scales of 1:5,000,000 and 1:10,000,000 depicting structural elements during successive divisions of the Pennsylvanian System, types and distribution of rocks deposited during each division, and specialized information such as probable source areas for sediments, coal, and evaporites.

WATER RESOURCES

The USGS conducts investigations, surveys, and research on the occurrence, quality, quantity, distribution, utilization, movement, and availability of the Nation's surface- and ground-water resources. This work includes investigations of floods and droughts and their magnitude, frequency, and relation to climatic and physiographic factors; the evaluation of available waters in river basins and ground-water provinces including water requirements for industrial, domestic, and agricultural purposes; the determination of the chemical and physical quality of water resources and the relation of water quality and suspended-sediment load to various parts of the hydrologic cycle; and special hydrologic studies of the interrelations between climate, topography, vegetation, soils, and urbanization and the water supply. One of the most important activities of the USGS is the systematic collection, analysis, and interpretation of data for evaluating the Nation's water resources. These data are computer processed for storage, retrieval, and dissemination of water information.

The USGS has the responsibility for coordination of national network and special water-data acquisition activities and the maintenance of a central catalog of water information for use by Federal agencies and other interested parties.

Research is conducted to improve the scientific basis of investigations in hydraulics, hydrology, instrumentation, and the chemical and physical properties of water. The research may be grouped in the following categories: (1) Properties of water, (2) the hydrologic cycle (drainage, runoff, and watersheds; evaporation, meteorology, and precipitation; flow, hydraulics, and streams; ground water; soil water; lakes and reservoirs; water and plants; erosion, sedimentation, and sediments), (3) irrigation and pesticides, (4) water management, (5) water-pollution effects, water-pollution sources, and water quality, (6) waste-water disposal, (7) water-resources planning and development, (8) water law, (9) environment, (10) corrosion, (11) data handling methods, and (12) digital-computer techniques, systems, and models.

A significant part of USGS water-resources activities is providing scientific and technical assistance to other Federal agencies where knowledge gained from USGS research projects may be helpful. When USGS interests are related to the interests of other agencies, USGS assistance contributes to the efficiency of their programs and encourages the maintenance of high standards of technical accomplishment.

The USGS develops ground- and surface-water technology and the technologies necessary for dealing with (1) the chemical, physical, and biological properties of water, and (2) the interrelation of these water-quality properties within the environment.

During fiscal year 1972, data on streamflow were collected at about 8,400 continuous-record discharge stations and at about 9,600 lake- and reservoir-level and partial-record streamflow stations. More than 4,000 maps of flood-prone areas in 46 States have been completed to date, and numerous pamphlets covering areas susceptible to flooding have been prepared. Studies of quality of surface water were expanded—approximately 4,560 water-quality stations in the United States and its possessions were involved. Parameters measured include those of selected major cations and anions, specific conductance or dissolved solids, and pH. Other parameters, measured as needed, include trace elements, phosphorous and nitrogen compounds, detergents, pesticides, radioactivity, phenols, BOD, and coliform bacteria. Streamflow records were collected at most of the water-quality stations, and water temperature was recorded continuously or at the time of sampling at about 4,000 water-quality stations. Sediment data were obtained at over 900 locations.

In 1972 almost 500 USGS scientists reported participation in areal water-resources studies and research on hydrologic principles, processes, and techniques. Nearly 300 of the studies in progress are classed as research projects. Of current water-resources studies, about 170 studies are directly related to urban hydrology problems; about 150 are indirectly related. Areal studies are being carried out in 860 locations covering 744,000 sq mi, including 587,000 sq mi of comprehensive river-basin planning studies. Ground-water studies have been made or are currently in progress for about two-thirds of the Nation. Scheduled measurements of ground-water levels were made in 16,000 network wells and 11,800 project observation wells; thus, periodic measurements were made in 27,800 wells. Studies of saline-water aquifers, particularly as a medium for disposal of waste products, are becoming increasingly important as are hydrologic principles governing the occurrence of brackish water in esturaries. Land subsidence due to ground-water depletion and possibilities for induced ground-

water recharge are under investigation in areas where the land surface has settled significantly.

The use of computers for research studies of hydrologic systems and for storing data continued to increase during fiscal year 1972. Records of about 245,000 station-yr of streamflow data and information on some 40,000 wells and 6,700 water-quality stations are available. The streamflow records and the quality-of-water records have been placed on approximately 40 magnetic tapes. Digital-computer techniques are used to some extent in almost all the research projects, and new techniques are being developed.

The water-resources activities selected by the USGS as its contribution to the International Hydrological Decade (IHD) were continued in1972, and a résumé of certain activities in the IHD program for 1972 concludes the water-resources section of this chapter. More detailed reports on some of the activities appear, where appropriate, in other sections.

The principal publications devoted to basic hydrologic data are in the following series of USGS water-supply papers: (1) "Surface-Water Supply of the United States," (2) "Quality of Surface Waters of the United States," and (3) "Ground-Water Levels in the United States." In addition to these basic-data reports, other series of water-supply papers describe the magnitude and frequency of floods of the entire country, by drainage-basin areas, and report noteworthy floods each year.

Investigations describing the occurrence of water as a natural resource are given in the following sections for the four regions of the United States (fig. 4) used by the USGS for administering the program.

ATLANTIC COAST REGION

Renewed interest in areal and basin hydrologic studies in the Atlantic coast region has resulted from a necessity to fulfill the requirements of those having the responsibility to resolve competing or conflicting interests of industry, agriculture, conservation, wildlife, and recreation, and of communities which share or are interested in the same water. There is an urgent need to understand aquifer systems and their interrelations with surface-water bodies, whether fresh, brackish, or salty. Studies of whole systems and parts of systems were recently completed or are underway in several areas—the Atlantic Coastal Plain, Long Island, the New Jersey wetlands, the Delmarva Peninsula, South Carolina, and southern Florida. Systems studies involving total water management in Puerto Rico are also underway. A mathematical model of the Ipswich River basin in Massachusetts is being used in the total management of that basin's water resources.

Figure 4.—Index map of the conterminous United States, showing areal subdivisions used in the discussion of water resources.

Digital and analog models are defining the hydraulics of bays and estuaries. The model of Port Royal Sound, S.C., is nearing completion. Model studies of Biscayne and Tampa Bays, Fla., are underway; a highlight of the Tampa Bay study is the successful use of newly developed bathymetric gear.

Many projects are environmentally oriented, such as sanitary-landfill studies in Maryland, New York, and Florida as well as urban-hydrology studies centered in Pittsburgh, Philadelphia, and the Connecticut River valley. Other projects such as a study of the effects of spraying treated sewage for agricultural purposes in Florida, emphasize recycling. Lakes, including Okeechobee and Apopka in Florida and Oneida in New York, are being studied by teams of limnologists, biologists, chemists, hydrologists, and hydraulic engineers. Items under investigation are the effects of drainage, stage fluctuations, pollution, and contamination on lakes and the effects of wind, current, and depth variation on mixing, turbidity, and algal growth in lakes. Causes and effects of natural and man-accelerated eutrophication are also being studied.

Rivers are being studied for dispersion of toxic or noxious substances and heat by time-of-travel and remote-sensing methods. Bottom sediments are being scanned more closely for trace elements, PCB, and other pesticides.

NEW ENGLAND

Ground-water resources of the Barre-Montpelier area, Vermont

A. L. Hodges, Jr., (USGS) and David Butterfield (Vermont Dept. of Water Resources) located and tested two aquifers that were suitable for development for municipal water supplies in the Barre-Montpelier, Vt., area. The first, in East Montpelier, has a transmissivity of about 40,000 sq ft per day, but analyses indicate that its water would require treatment for removal of excess manganese. The second, in Northfield, has a transmissivity of 65,000 sq ft per day and analyses indicate that its water meets USPHS standards for public water supplies.

Safe yield of both aquifers is limited by the effects of pumpage from the aquifers on the base flow of adjacent rivers. The Winooski River overlies and is directly connected to the East Montpelier aquifer. Large withdrawals of ground water during drought could reduce the base flow of the river to less than the 0.2 cfs per sq mi required by the Vermont Department of Water Resources. The Northfield aquifer is generally separated from the Dog River by bedrock; however, if pumping were heavy, the aquifer could be recharged from the river along 500 ft of the channel. The calculated maximum rate of recharge is 0.5 cfs; however, during low flow this amount may lower the flow of the river below State-imposed limits.

Ground-water resources of the White River Junction area, Vermont

A total of 13,863 ft of subsurface profiling by the seismic-refraction method at eight sites indicated that unconsolidated deposits as thick as 240 ft were largely lacustrine silt and clay, according to A. L. Hodges (USGS) and David Butterfield (Vermont Dept. of Water Resources). Auger borings totaling 1,607 ft were made at seven sites in order to confirm subsurface geology and to install observation wells. Potential aquifers at three sites were tested by pumping 8-in. wells. At Hartland, the transmissivity of an aquifer adjacent to Lulls Brook is about 20,000 sq ft per day; the water quality meets USPHS standards for public water supplies. At Hartford, a test well penetrated 55 ft of saturated permeable material in a burial channel of the Connecticut River. Although the tests are incomplete, the apparent specific capacity is 16 gpm per ft of drawdown. Water quality in the Hartford aquifer is acceptable except for a concentration of manganese approximately 10 times the limit recommended by USPHS. A well at Norwich on the longitudinal axis of an esker, about 200 ft west of the Connecticut River, has a specific capacity of 66 gpm per ft of drawdown. The saturated aquifer thickness is at least 84 ft. Chemical analyses of the water are not yet available.

Hydrology and water resources of the Charles River basin, Massachusetts

Water use is increasing in the Charles River basin because of increases in population and in per capita water use, according to E. H. Walker, W. W. Caswell, and S. W. Wandle.

Most town wells in the basin yield 300 gpm or more from sand and gravel aquifers which are, on the average, only about 45 ft thick, but hydrologic conditions would permit development of large supplies of water from wells by induced infiltration in places in the urbanized, lower part of the basin. However, certain constraints deter such development. For example, more pumping from aquifers near ponds would lower water in ponds to levels that local interests would not tolerate. Also, much of the induced water would eventually be diverted out of the basin by sewers, resulting in further depletion of the low flow of the river. Further, the dissolved-solids and chloride content in the river and its tributaries has risen substantially in recent years, making the water less desirable than it once was.

Mathematical modeling of Ipswich River basin, Massachusetts

A simulation model used to study alternative ways of supplying towns dependent on the Ipswich River basin for water shows that no combination of individual municipal water-supply projects will meet the anticipated combined demand of 1980, according to I. C. James II and A. W. Burns. Different supply alternatives, which allow for different staging sequences, include (1) construction of a major storage reservoir in the basin, (2) importation of water from the Merrimack River, and (3) extension of the Metropolitan District Commission (Boston) supply system into the basin. The lead time necessary for planning, financing, and constructing some of

the facilities requires an early decision concerning the ultimate regional-development strategy that must be used to prevent preemptive purchase of reservoir sites for local developments.

Evaluation of stratified-drift aquifers in southeastern Connecticut

Hydrogeologic data collected by R. L. Melvin from more than 250 test holes are being used to evaluate potential yields from stratified-drift aquifers in southeastern Connecticut. The transmissivity and saturated thickness of the most promising one, located in the lower part of the Shunock and Pawcatuck River valleys, have been determined. Mathematical models indicate that, under present conditions, the stream-aquifer system is capable of yielding about 10 mgd.

Hydrology of a proposed hydroelectric pumped storage site, Canaan, Connecticut

M. A. Cervione, Jr., is evaluating hydrologic data to determine the feasibility of constructing a 1-million-kilowatt pumped-storage hydroelectric facility in the 11-sq-mi drainage basin of Wangum Lake Brook in the sparsely settled hills of northwestern Connecticut. Runoff in 1971 was about 20 in.

Preliminary analyses, based on monthly sampling for conductivity, pH, temperature, DO, and bacteria, indicated that the quality of the surface water in the area is excellent. Additional sampling at low flows, which involved spectrographic analysis for trace elements and analyses of pesticides, herbicides, and total organic carbon, indicated that the quality of the water is satisfactory.

Water resources of the Farmington River basin, Connecticut

Study of auger samples and drillers' logs by H. T. Hopkins and D. B. Meade revealed several potentially good locations for ground-water development southward from Drumlin Hills to Crowleys Corner. The saturated section of sand and gravel beds is as thick as 60 ft in places but is generally about 40 ft.

Analyses of water samples from stratified drift along the Pequabuck River indicated significant concentrations of dissolved copper, lead, and zinc near industrial disposal pits. In general, surface water is of excellent quality except in the highly industrialized Bristol area.

Water resources of the lower Connecticut River basin

Studies by L. A. Weiss and J. W. Bingham of the lower Connecticut River basin show that large supplies of ground water are obtainable from thick but discontinuous deposits of sand and gravel along the river. Yields as great as 1,570 gpm are available from individual wells suitably developed and situated to induce infiltration of stream water through coarse-grained material. The most productive deposits seem to be on the west side of the river. Brackish ground water may be a problem in reaches south of East Haddam. Also, between Middletown and Saybrook, iron concentration in ground water is generally high enough to require treatment for municipal or industrial use.

Specific capacities of about 300 wells tapping Triassic sedimentary rocks average 0.07 gpm per ft of drawdown, compared with an average of 0.22 gpm per ft of drawdown for 500 wells in similar rocks in the adjacent upper Connecticut River basin.

NEW YORK

Nassau County ground-water system

Channels cut in Upper Cretaceous deposits and later filled with heterogeneous glacial deposits have been delineated in greater detail as a result of remapping of aquifers and confining beds by N. M. Perlmutter. Some channels that cut down to bedrock in the northern part of Nassau County provide paths for interaquifer movement of water, whether fresh or contaminated. Preliminary results of X-ray diffraction of clay samples suggest possible use of the clay in differentiating between deposits of Pleistocene and Cretaceous age.

Change in head in the Lloyd aquifer, Long Island

Head in the Lloyd aquifer has declined as much as 40 ft in western Long Island in the last 70 yr, according to G. E. Kimmel. The decline resulted from withdrawal of about 300 billion gal of water. The loss in storage, however, is estimated to be only 0.5 percent of the total withdrawal.

PENNSYLVANIA

Urban and rural ground-water hydrology in the northern part of the Cumberland Valley

Preliminary statistical evaluation of the specific capacity of 133 randomly selected wells in carbonate rocks between Shippensburg and the Susquehanna River indicates excellent potential for developing ground-water supplies according to A. E. Becher and W. S. Wetterhall. The median specific capacity is 3 gpm per ft of drawdown. The quartile values of the cumulative frequency distribution of specific capacity are 0.2 and 20 gpm per ft. At least 10 percent of the wells should be capable of yielding 500 gpm; several are capable of sustaining yields of more than 1,000 gpm.

Reconnaissance data indicate that there are at least two areas—one between Plainfield and Carlisle and another in the vicinity of Mechanicsburg—of general bacterial pollution and abnormally high dissolved-solids content of ground water. A major gasoline spill has seriously degraded the water quality of an area east of Mechanicsburg.

MARYLAND, DELAWARE, AND VIRGINIA

Hydrology of Triassic rocks in Frederick, Carroll, and Montgomery Counties, Maryland

The Newark Group, of Late Triassic age, consists of a sequence of stream-deposited sedimentary rocks, chiefly arkosic sandstone, siltstone, shale, limestone-pebble conglomerate, and quartz-pebble conglomerate. According to L. J. Nutter, water occurs chiefly along joint planes and in the lower part of the weathered overburden. The arkosic sandstone and conglomerate beds generally yield more water to wells, presumably because they are more highly jointed than the shale and siltstone. Apparently, fairly extensive solution cavities have developed in some places in the limestone-pebble conglomerate. Several high-yielding wells in the conglomerate indicate that it has a good potential for moderately large ground-water supplies.

Onshore test drilling and offshore acoustical profiling near Ocean City, Maryland

J. M. Weigle (USGS) reported that a good correlation was obtained when results of onshore test drilling were compared with those of nearby offshore acoustical profiling by David Duane (U.S. Army Corps of Engineers). Relative parallelism and continuity of acoustically reflective surfaces in the uppermost 200 to 300 ft of sediments indicate that the slope of the bedding planes under the mainland and barrier islands continues several miles seaward with little change. Eastward-trending faults or paleochannels are speculated to occur in the uppermost 200 to 300 ft of sediments beneath Ocean City and Assateague Island but were not confirmed by preliminary inspection of nearshore acoustical profiles.

Hydrogeology of the carbonate rocks, Frederick and Hagerstown valleys, Maryland

In a study of a fairly extensive area underlain by folded Cambrian and Ordovician carbonate rocks, L. J. Nutter found that the stream network provides valuable data concerning the hydrogeology. Average annual precipitation in one basin is about 35 in., and analysis indicated total runoff is 12 in. and evapotranspiration is 23 in.

Hydrograph separation of records for 1967 from three gaging stations showed that ground-water discharge is about 80 percent of the total runoff. Colluvium along bordering mountain areas stores significant quantities of water which slowly recharge the underlying carbonate rocks. Many streams lose a substantial part of flow to the underlying carbonate rocks within half a mile of the mountain fronts, and a few streams flow directly into sinkholes. Well yields and specific capacities are extremely variable, but moderately large water supplies can be obtained if well sites are carefully selected.

Extensive seasonal cone of depression in coastal Maryland

According to J. M. Weigle, large-scale seasonal withdrawals of water from the deep (300 ft) confined Manokin aquifer in Ocean City, Md., affect the hydrostatic head of the aquifer to a distance of as much as 6 mi. A corresponding transient cone of depression, extending that distance or farther from the center of pumping, developed in the potentiometric surface of the Manokin aquifer. The cone of depression and its seasonal development and recovery are being analyzed in a thorough cyclic aquifer test as part of a geohydrologic study of the area.

Exploration for fresh ground water on Delmarva Peninsula

In order to learn more about the fresh-water section of the subsurface of the Delmarva Peninsula, drill cuttings and geophysical logs were obtained by E. M. Cushing and I. H. Kantrowitz from five test wells. Data were obtained from a test well drilled to a depth of 3,000 ft near Atlantic, Va. Fresh ground water (less than 1,000 mg/l dissolved solids) was available only to a depth of 390 ft. In a 1,040-ft test well about 3 mi south of Laurel, Del., fresh water occurred to a depth of 470 ft. Electric logs run in an 864-ft test well near Sandtown, Del., in a 780-ft test well near Stevensville, Md., and in a 1,600-ft test well drilled for Cambridge, Md., showed that all these aquifers contain fresh water.

Ground-water conditions in the Franklin area, Virginia

Heavy industrial pumpage from Atlantic Coastal Plain aquifers of Cretaceous age continued near Franklin during 1971. G. A. Brown and O. J. Cosner made a new potentiometric map of the Franklin area from water levels measured in December 1971. Comparison of this map with the potentiometric map for September 1970 indicates that, because of reduced pumpage during 1971, levels rose slightly in wells near the center of the cone of depression at Franklin. Water levels declined as much as 5 ft in wells outside the immediate vicinity of Franklin, however, because the cone of depression had not yet reached equilibrium with the withdrawals at Franklin.

A shallower cone of depression north of Suffolk at the Lake Prince well field of the city of Norfolk was noted late in 1970. Withdrawals of 10 to 15 mgd caused water levels to decline as much as 9 ft in a 3-month period. No water was pumped from the Lake Prince well field in the last 9 months of 1971. As a result, the cone was not apparent on the December 1971 potentiometric map.

A multiple-screened well south of Suffolk was drilled to a depth of 1,920 ft. Six water samples from depths ranging from 947 to 1,879 ft were saline water with chloride contents ranging from 6,800 to 12,000 mg/l.

WEST VIRGINIA

Water resources of the Potomac River basin, West Virginia

W. A. Hobba, Jr., E. A. Friel, and J. L. Chisholm reported that average annual precipitation is 38 in. in the basin. Of this amount, 25 in. becomes evapotranspiration, 8 in. becomes ground-water recharge, and 5 in. becomes direct overland runoff. Runoff in streams ranges from 0.4 to 2.2 cfs per sq mi. The median 7-day low flows range from less than 0.03 to more than 0.15 cfs per sq mi.

Folded and faulted crystalline rocks, sandstone, shale, siltstone, and carbonate rocks characterize the geology of the area. The carbonate rocks of Berkeley and Jefferson Counties are the best aquifers and yield more than 600 gpm to individual wells tapping cavernous zones. The shale in the central part of the basin has the poorest potential for furnishing water. Wells have been drilled 400 to 1,000 ft into shale without obtaining a usable quantity of water.

The chemical quality of both surface water and ground water ranges from very poor to excellent. In places, water from the shale contains as much as 7,900 mg/l dissolved solids. In other places, water from the coal-bearing rocks contains sulfate and iron in excess of 2,000 mg/l and 300 mg/l, respectively. Surface water and ground water of very poor quality are generally found in the same areas.

Reconnaissance of water resources of Upper New River basin, West Virginia

According to W. E. Clark, P. M. Frye, and J. L. Chisholm, a well inventory conducted in the basin indicated that sufficient ground water of good quality is available in most places for industries having small water requirements and for agricultural and domestic purposes.

NORTH CAROLINA

Monthly water balance of the Neuse River Basin

The long-term average distribution of precipitation, evapotranspiration, and runoff throughout the year for the upper Neuse River basin in North Carolina was obtained by A. L. Putnam by the computation of a monthly water balance, as described by Thornthwaite and Mather (1957). This balance study resulted in runoff values that compare closely with streamflow records for three long-term (43 yr of record each) gaging stations in the Neuse River headwaters. The computed monthly runoff distribution depicted fairly well the high flow period in the winter, recession in the spring, and gradually diminishing low flow during the summer and fall. The computed monthly runoff distribution resulted in values that ranged from an average of 26 percent above to 32 percent below the observed monthly runoff. The total computed annual runoff, however, was only 7 percent below the observed long-term average annual runoff.

The study also resulted in evapotranspiration values that compared very well with lake-evaporation data reported by W. L. Yonts (oral commun., 1971) for Lake Michie, which is an impoundment of a major tributary to the Neuse River. The computed monthly evapotranspiration was lower than the observed monthly lake evaporation except during the late spring and summer, when vegetation demands are great.

The monthly water balance described by Thornthwaite and Mather (1957) seems to be a useful tool for determining the distribution of precipitation, evapotranspiration, and surface runoff for ungaged streams.

Deep test well at Cape Hatteras

The maximum depth of the fresh-water lens on the narrow (2,000 ft or less) barrier-beach islands of North Carolina's Outer Banks is about 20 ft, according to M. D. Winner, Jr. At Cape Hatteras, however, Hatteras Island is as wide as 3 mi, and the depth of fresh water is known to be in excess of 100 ft and possibly as much as 200 ft in the center of the island.

A test hole 570 ft deep was drilled at the Buxton maintenance area well field in the central part of the island. Geologic samples were taken, electric and gamma-ray logs were run, and water samples were collected from several strata to determine the maximum depth of fresh water and to investigate the deeper sediments and how they might affect the upward movement of salty water into the fresh-water-bearing sand beds. Information obtained from the electric log is supplemented by data from an earlier electric log that started at about the 500 ft depth.

The maximum depth of fresh water was found to be about 120 ft, grading to brackish water at the bottom of the upper sand aquifer at 135 ft. A clay bed which extends from 135 to 180 ft is thick enough to prevent vertical movement of salty water from the deeper aquifers. Water from the interval between 196 and 206 ft contained 400 mg/l chloride, and an open-end observation well that bottomed at 384 ft in limestone yielded water containing 9,400 mg/l chloride.

SOUTH CAROLINA

Hydrogeology of the Coastal Plain

According to G. E. Siple, tests in wells tapping the principal clastic aquifer system (the Tuscaloosa Formation) of the Coastal Plain indicated that in central Barnwell County the basal deposits of Cretaceous age can be divided into three aquifers separated by dark-gray and black confining clay beds. Previously, the highest yield (2,900 gpm) from a single well was that recorded from a test well in the principal carbonate aquifer in the lower part of the Coastal Plain, but the well in Barnwell County was pumped at 3,300 gpm, thus making it the highest producing well in the State. The specific capacity of this well, however, is appreciably lower than that of the

well in limestone. The Barnwell test was developed to steady-state conditions and indicated a transmissivity of 145,000 to 195,000 gpd per ft and a storage coefficient of 2.5×10^{-4}. An evaluation of the cone of depression developed by long-term (7 yr) pumping in Orangeburg County (adjacent to Barnwell County) indicated values of a similar magnitude for the transmissivity and storage coefficient of the same aquifer system.

Intensive development of the sand aquifers of Taylor and Austin age in the northern to central parts of the coastal area has increased the chloride concentration in waters from these aquifers.

Production from rock wells, York County

According to P. W. Johnson and C. A. Spiers, wells drilled below 250 ft in crystalline rocks in an area in York County added significantly to the water intercepted. Twenty-two 8-in. wells were drilled in the county, 20 of which ranged in depth from 500 to 700 ft. Of the two remaining, one is a 280-ft well that yields 20 gpm, and the other is a 480-ft well that yields 300 gpm. Eleven of the wells yield from 100 to 370 gpm, one yields 80 gpm, and one yields 60 gpm. The remaining wells yield from 2 to 40 gpm. The wells are located near Lake Wylie, a manmade reservoir, close to the North Carolina State line.

Not enough is known concerning the nature and attitude of the deep faults and (or) fracture system to rule out recharge from the lake, but similar recharge from precipitation through a high-angle fault or fracture system could produce water at these depths downdip. A shallow rock well 20 mi from Lake Wylie was deepened to about 500 ft, and the yield was increased from 5 to 150 gpm. Geophysical logging is planned to determine, if possible, the trend and pattern of the producing zones. If high-angle faults are found to relate to water zones, deeper wells could increase water production considerably.

GEORGIA

Salt-water encroachment, Glynn County

Temperature-conductivity logs of two wells in a large industrial well field in Glynn County show that water high in chloride content is entering the well field at different rates and along different paths in the two water-bearing zones of the principal artesian aquifer, according to E. A. Zimmerman and R. E. Krause. A well near the center of the field yields water from the upper water-bearing zone with a specific conductance of 1,500 μmhos. The specific conductance of water from the lower water-bearing zone tapped by this well is 800 μmhos. The chloride content of samples collected from the upper zone ranged from 145 to 189 mg/l; samples from the lower zone ranged from 47 to 59 mg/l.

The second well, which is located at the edge of the well field that is nearest to the area reported to contain water with high chloride values, yields water ranging from 1,500 to 2,600 μmhos in specific conductance, but the specific conductance increases about 1 μmho per foot of depth. Thus, it seems that the water high in chloride content has entered both zones at the edge of the field but only the upper zone in the middle of the field.

FLORIDA

Sand-and-gravel aquifer hydrology in the Pensacola area

Static water levels in wells in the sand-and-gravel aquifer in the Pensacola area are often substantially lower than the water table, but long-term records of water levels show little evidence of change that cannot be attributed to variations in the amount of precipitation.

Henry Trapp, Jr., reports that increased concentration of nitrate in water from the sand-and-gravel aquifer roughly parallels the increased concentration of population. Sewer leakage, septic tanks, and industrial pollutants may be sources of the nitrate.

Contamination, not shortage, the most probable future water problem in Marion County

Virtually all water in Marion County comes from the highly permeable Floridan aquifer. The aquifer is recharged by local rainfall infiltrating a cover of sand and clayey sand which, in most places, is several tens of feet thick, according to G. L. Faulkner and Warren Anderson. Water in the Floridan aquifer is abundant, and the supply is relatively stable. However, because of the local recharge characteristics, care must be taken to avoid contamination of the aquifer as the area is being developed. Sanitary landfills and sewage-treatment facilities, ideally, would be located and designed to take maximum advantage of the natural-filtration characteristics of the sandy cover over the limestone aquifer. Geohydrologic maps, prepared as a part of the investigation of the water resources of the county, provide information useful in planning waste-disposal facilities least likely to contaminate the aquifer.

Water resources of Seminole County

According to C. H. Tibbals, preliminary analyses of data indicate that, in at least one area of southwest Seminole County, the upper part of the Floridan aquifer is polluted by sewage or sewage leachate and is unsuitable for public water supplies. The source of the pollution has not yet been determined. As a result, the affected public-supply wells have been deepened, and the upper, polluting zone of the Floridan aquifer has been sealed off by casing.

Digital modeling of the aquifer system in Pasco, northwest Hillsborough, and northeast Pinellas Counties

Data from three aquifer tests in southern Pasco County were

analyzed by a digital (leaky-aquifer) model. The results indicated values of 150,000 gpd per ft for transmissivity, 4×10^{-5} for storage coefficient, and 2×10^{-3} gpd per cu ft for leakage, according to A. F. Robertson.

Historic artesian water-level trends were approximated fairly well in initial runs, but the need for more data to evaluate the various parameters relative to the confining layer is indicated. A dense clay layer directly overlies the limestone and, in northwest Hillsborough County, is about 5 ft thick. This clay, however, is absent in some of the test holes drilled to date but is an important part of the confining material in most of the study area.

Hydrologic effects of ground-water withdrawal near Tampa Bay

Within the past 20 yr, increased urban and agricultural development has resulted in greater ground-water withdrawal from the Floridan aquifer in southwest Hillsborough County. A. D. Duerr reported that the potentiometric surface near Tampa Bay has been lowered 10 ft during this period. Consequently, the threat of salt-water encroachment is growing. In general, wells in the coastal part of the county, where water levels have declined 10 ft since 1952, now yield water that has a chloride concentration as great as 480 mg/l, or double that previously reported.

Hydrology of the Floridan aquifer, Clearwater-Dunedin

According to R. N. Cherry, aquifer tests indicated that the permeability of the shallow aquifer in the Clearwater-Dunedin area was about 250 gpd per sq ft and that the transmissivity of the Floridan aquifer was about 125,000 gpd per ft.

Hydrology of Lake Magdalene

During the 1970–71 drought, the stage of Lake Magdalene in Hillsborough County declined at the same rate as the local water table, according to J. D. Hunn and R. C. Reichenbaugh.

The lake bottom has an irregular surface which contains several deep depressions that are probably former sinkholes. Many elongated depressions, the result of dredging, occur adjacent to the shore. The bottom is covered by sediments that consist chiefly of organically rich silt.

Pesticides were found in samples of the lake-bottom sediment. Estimated chlordane contents were 80 μg/kg and 20 μg/kg in the two samples analyzed. Smaller concentrations of dieldrin and other pesticides were also found.

Water resources of Hardee County

W. E. Wilson reported that mapping of the potentiometric surface of the Floridan aquifer in May 1971, during a period of extended irrigation pumping, revealed a major trough in the surface in Hardee County. The lowest altitude in the trough, which extended into adjacent Manatee County, was about 20 ft above mean sea level. Remapping in September 1971, after the irrigation season, showed that the potentiometric surface had recovered 20 to 30 ft in Hardee County and that the trough was no longer present.

Water resources of Osceola County

Present use of water from the Floridan aquifer is increasing in Osceola County, but chloride content of the water evidently has not increased, according to J. M. Frazee, Jr. Further studies are now underway to map the chloride levels throughout the county and to document trends within the Floridan aquifer.

Urban hydrology of Sarasota County

Horace Sutcliffe, Jr., reported that an evaluation of the water resources immediately adjacent to Venice, Fla., will provide the data necessary to plan for expansion of the city water system. By means of test drilling east of the city, sources of water of acceptable quality and of adequate quantity to satisfy immediate needs where located. Fourteen production wells yielding as much as 100 gpm will be available for use by the beginning of the tourist season in 1972. Additional water for the city will be needed, however, in the near future.

The city of Sarasota's Verna well field is about 17 mi east of town, at the highest elevation in the county, in a recharge area. The upper 130 ft of material underlying the well field consists of sand, clay, and thin beds of limestone, all containing water of good quality. Fourteen test wells have been drilled, and three of the wells have yielded 100 to 250 gpm. However, only three of the wells have yielded sand-free water with the test screens used.

Residential developments served by the Englewood Water District have markedly increased the demand on the public water supply of Englewood. Preliminary maps of the chemical quality of water from the two uppermost artesian aquifers indicate that saline water is intruding from old wells. These wells are uncased in the lower parts and allow the upward movement of highly mineralized water from the deeper aquifers into relatively unmineralized shallow aquifers. Mapping the chloride and sulfate content and the specific conductance of water from selected shallow-aquifer wells indicates the general location of many of the older, deeper wells. Future water-supply development undoubtedly will be limited to uncontaminated areas. Preliminary analyses of data indicate that there is little direct saline-water intrusion from the Gulf of Mexico or from estuaries.

Water resources of eastern Palm Beach County

Hydrologic investigations by H. G. Rodis, J. J. Schneider, and L. F. Land indicated that population growth is causing an increasing demand for fresh-water resources in Palm Beach

County. The drought during the early part of 1971, together with increased ground-water withdrawal and land drainage, caused ground-water levels to reach alltime lows in some areas. Sea-water intrusion in coastal areas caused some supply wells to be temporarily shut down. Analyses of water samples show that water in many canals and lakes is becoming increasingly polluted with nutrients and coliform bacteria. The most severe pollution seems to be in the Earman River area.

Streamflow in the Big Cypress watershed during wet and dry seasons

A part of the water needs of Everglades National Park and lower Gulf Coast communities are met by water that drains from the Big Cypress watershed. The amount of drainage varies considerably. H. J. Freiberger reported that during November 18–20, 1969, a fairly wet period, about 4,000 cfs of water drained from the Big Cypress watershed. On March 9, 1971, during a very dry period, less than 100 cfs of water drained from the watershed.

Hydrology of western Collier County

A forecast indicates that the population of western Collier County may increase from 27,000 in 1972 to 180,000 by 1980. H. J. McCoy reported that the shallow aquifer 10 to 15 mi inland from the Naples well field in western Collier County has the capacity to provide, with proper development and management, enough ground water of good quality to meet water demands in 1980; however, the maximum withdrawal capacity of the shallow aquifer in the Naples well field will probably be reached by that time.

Mapping of land use and vegetation in the Big Cypress Swamp area

Land use in the Big Cypress Swamp area of southwest Florida was studied by J. T. Armbruster. A map, based on aerial photographs, was prepared. It showed areas of residential, proposed residential, agricultural, and undeveloped land use. Reportedly, about 25 sq mi is used for residences, about 200 sq mi will be used for proposed residential development, and about 200 sq mi is used for agriculture.

B. F. McPherson delineated 10 major vegetal associations with the aid of aerial photography and ground observations in the undeveloped regions of the Big Cypress Swamp area. These associations are related to hydrologic features. The map is color coded by vegetal type.

Water resources of the Hallandale area

The configuration of the water table in Hallandale is greatly influenced by the Intracoastal Waterway, the Oleta River, Snake Creek Canal, and municipal pumping, according to H. W. Bearden. During the dry season, the Biscayne aquifer is recharged by Snake Creek Canal. Pumping-test data indicate that the aquifer is highly permeable. Transmissivity ranges from 2.0 to 2.5 mgd per ft. In the southwest part of the city, salt water has intruded the aquifer by infiltration from the upper reaches of the Oleta River.

Water management and water supply, Fort Lauderdale

H. J. McCoy and C. B. Sherwood reported that the feeder canal from Middle River Canal through the large (40 mgd) Prospect well field in north Fort Lauderdale recharged the well field significantly during the record dry period from January to June 1971. Improvements in the connection between the Middle River Canal and the inland water-conservation areas will more than double the recharge potential of the Middle River Canal to the well field, which will become increasingly important as the well field is expanded to supply central Broward County with more than 100 mgd of treated ground water.

Water resources of the Hollywood area

Chemical analyses of water from test wells near Hollywood's 60-ft-deep supply wells showed water of better quality could be obtained below a depth of 100 ft, according to H. W. Bearden. Test drilling in the area of proposed well-field expansion in the southwest part of the city indicated that permeable limestone and shell beds at depths of 134 to 159 ft constitute an excellent aquifer.

During the dry season, the chloride content of Hollywood Canal is more than 10,000 mg/l. Control of salt water in the canal would require both a salinity barrier and fresh-water replenishment.

Dade County deep-well disposal

F. W. Meyer assisted Dade County representatives in planning research and monitoring systems to insure safe and efficient operation of a proposed deep-well injection system for waste disposal. This system along with additional treatment facilities will form part of the county's master plan to provide sanitary sewers and to abate pollution of surface-water bodies.

PUERTO RICO

Ground-water resources of the San Juan metropolitan area

In the San Juan area, H. R. Anderson defined the productivity of the Tertiary limestone, which is limited because of sea-water intrusion, and reported the presence of a sand-marl artesian aquifer below the limestone. Correlations along the north coast, 20 to 30 mi west of San Juan, show that limestone at depths of 1,000 to 1,500 ft may be part of the

same sand-marl aquifer system. The Cibao Formation is apparently the consistent confining layer. The sand-marl aquifer probably contains fresh water in coastal areas where the upper limestone is prone to sea-water intrusion.

Analog model of Yabucoa Valley

An analog model of the Yabucoa Valley alluvium indicates that inflow and outflow of water is 9 mgd, according to T. M. Robison and R. B. Anders. The maximum practical yield under unsteady-state conditions is estimated to be 16 mgd, 11 mgd of which is salvaged water-table evaporation and 5 mgd of which is intercepted stream discharge and induced stream recharge. The model will be tested at a projected pumpage of 12.6 mgd for a 30-yr period.

Stored water in the aquifer is estimated to be 60 billion gal, most of which is fresh.

MIDCONTINENT REGION

Water-resources investigations in the midcontinent region are increasingly oriented toward the management of the hydrologic system and the collection and synthesis of water data. In response to water-management information needs, modeling techniques are used to simulate, under varying conditions, the effects of various projected rates of withdrawals for both regional and local planning purposes.

The relations of physical and chemical properties to the hydrologic properties are being studied in order to establish guidelines for reservoir design and to establish criteria for recreational utilization and antipollution activities.

INTERSTATE STUDIES

Effect of ground-water discharges on recreational value of cold-water rivers

Recreational values of cold-water rivers in the Great Lakes region have been under study by G. E. Hendrickson, R. L. Knutilla, and C. J. Doonan. Some beneficial effects were found to depend to a large degree on the amount of ground-water discharge, which stabilizes streamflow and holds down water temperatures in rivers during summer months. Constant flow and cool water are especially beneficial to sport fishing, and an adequate flow contributes to the attractiveness of placid streams. The inflow of ground water is less effective, normally, in producing waterfalls, rapids, and other scenic features in rivers used for recreation.

Ground-water development in the Ohio River region

Results of a broad-perspective study of the ground-water resources of the Ohio River region indicated that the large, important, exploitable ground-water resources of the region should play a significant role in the development of the region's total water resources. According to R. M. Bloyd, Jr., some of the principal conclusions of the study are: (1) Utilization of the ground-water resources in 1965 was only a small percentage of the potential, (2) the Wabash subbasin, which includes the White River drainage, has the highest potential of all subbasins in the Ohio River region for additional ground-water development, (3) the highest yielding aquifer in the Ohio River region is the outwash and alluvial aquifer in the Mad River drainage area in Ohio, (4) about 110 trillion gal of potable ground water (water containing less than 1,000 mg/l of dissolved solids) is in storage in the region, and (5) nearly all densely populated areas have the potential for obtaining large supplies of ground water.

IOWA

Appraisal of the Mississippian aquifer

Although the Mississippian aquifer underlies about 60 percent of the State, a recently completed study by W. L. Steinhilber (USGS) and P. J. Horick (Iowa Geol. Survey) revealed that the aquifer presently is the major source of water in only 15 percent of its area of occurrence. Approximately 11 mgd is being withdrawn from this aquifer. Conservative estimates of storage and recharge indicate that much larger quantities are available for development.

LOUISIANA

New public water supply for Laplace

Test drilling in northern St. John the Baptist Parish has revealed a deep fresh-water-bearing sand that can be developed to furnish water of excellent quality for the public water supply at Laplace, La., according to D. C. Dial. Six test wells were drilled along U.S. Highway 51 between Manchac and Laplace to determine the availability of fresh ground water for public-supply use. The test area was in the zone marking the southern limit of fresh water in Louisiana except in the shallowest aquifer.

Red River alluvial aquifer is of Pleistocene and Holocene age

Results of a study by A. H. Ludwig in the Red River valley in Louisiana indicate that the alluvial aquifer is generally composed of two distinct geologic units. The upper section, considered locally to be of Holocene age, is composed primarily of fine to medium, gray sand, and in some places contains fine gravel near the base. The lower section, considered to be of Pleistocene age, generally is composed of coarse or very coarse, brown or yellow sand, grading downward to gravel at the base of the alluvial section. In most places a layer of dense blue-gray clay, which may be as much as 25 ft thick, marks the upper part of the lower section, although in some

areas it is thin or absent. In northwest Louisiana, the clay layer is present only in the deeper parts of the alluvial section. In the vicinity of Shreveport, where the clay layer is present, the Pleistocene section below it is less than 10 ft thick, whereas southeast of Alexandria, the Pleistocene section may be as much as 150 ft thick.

Five miles south of Manchac, a deep (3,200 ft) test well confirmed the existence of a fresh-water-bearing sand between depths of 2,880 and 2,980 ft. Northward, the number of sands containing fresh water increases progressively with distance. South of the test well, fresh ground water is available from the "400-ft" and the upper part of the "700-ft" sands of the New Orleans area. Water from the "400-ft" sand is of marginal quality for public-supply use.

MINNESOTA

Glacial drift is source of water in Mesabi Range

Based on detailed mapping of stratigraphic relationships of drift, quantitative hydrogeologic maps (isopachous and isotransmissivity) were prepared of glaciofluvial deposits at four stratigraphic horizons. Streamflow data were analyzed, and base flow indicates that about 5 in. of water recharges the ground-water system annually. Using this figure and considering the distribution of aquifers, T. C. Winter estimated that 40 to 80 mgd could be developed from drift sources in the 1,400-sq-mi area of the Mesabi Range.

Water budget developed for eutrophication study of Shagawa Lake

A water budget study of Shagawa Lake is being made in conjunction with a research project on the control and abatement of accelerated lake eutrophication by the Water Quality Office of the Environmental Protection Agency. According to D. W. Ericson, a preliminary water budget for winter periods when evaporation losses are at a minimum indicates that there is little ground-water seepage to the lake.

When inflow, outflow, and change in lake storage were compared for the winter periods of the 1968, 1969, and 1970 water years, the maximum budget residual for these three winter periods was 900 acre-ft (3 cfs) of excess outflow in 1969. Average outflow discharge for this period was approximately 75 cfs.

In the Shagawa Lake area, Precambrian crystalline rocks are exposed at the surface and overlain locally by deposits of glacial drift. Test augering in the glacial drift adjacent to the lake indicates that the unconsolidated deposits are thin and composed mainly of silt and clay, suggesting little ground-water movement through them.

Water resources of river basins in southern Minnesota

Studies in progress in south-central Minnesota by H. W. Anderson, Jr., indicate the presence of several bedrock valleys filled with more than 500 ft of glacial deposits on both sides of the Minnesota River. These glacial deposits receive recharge from the St. Peter Sandstone and the Jordan Sandstone, which are recharged through overlying limestone formations.

According to W. L. Broussard, water-quality studies in the Blue Earth River watershed show dissolved-solids content generally greater than 1,000 mg/l in the area west of the river where sulfate-type water is typical and less than 500 mg/l in the area east of the river where bicarbonate-type water is typical.

D. F. Farrell reported that analysis of precipitation data for the river basins in southern Minnesota showed that annual runoff ranged from 27 in. to 31 in.

Water resources of the Rum, Mississippi-Sauk, and Crow River basins

According to G. F. Lindholm, J. O. Helgeson, D. W. Ericson, and D. F. Farrell, water-resource investigations in the Rum, Mississippi-Sauk, and Crow River basins revealed that streamflow in the Rum River basin is sustained by water released from storage in surficial outwash deposits in the southern third of the basin and from Mille Lacs in the headwaters area.

In the Rum and Mississippi-Sauk basins the discharge from the till deposits ranged from no flow to 0.05 cfs per sq mi during the low-flow period in the summer. During the same period, discharge from the surficial outwash deposits ranged from 0.10 to 0.27 cfs per sq mi.

In the southern third of the Rum basin and extreme eastern parts of the Mississippi-Sauk and Crow basins, the sandstones of Precambrian and Cambrian age are good sources of ground water. Elsewhere ground water is normally obtained from sands and gravels in the glacial drift. The surficial outwash deposits are a relatively underdeveloped source of large amounts of ground water in some parts of the Rum and Mississippi-Sauk basins. Yields to wells of as much as 1,000 gpm are theoretically possible where large saturated thicknesses of outwash deposits occur.

MISSOURI

Water resources of the St. Louis area

According to L. F. Emmett, wells yielding more than 50 gpm of potable water can be developed from consolidated aquifers throughout the western one-third of St. Charles County, the extreme western part of St. Louis County, and the southwestern three-fourths of Jefferson County. In these areas, wells in the Potosi Dolomite have yielded a maximum of 500 gpm. Wells in the Gasconade and Roubidoux Dolomites have yielded a maximum of 300 gpm. Yields up to 140 gpm have been reported from wells penetrating the St. Peter Sandstone.

Water resources of west-central Missouri

According to E. E. Gann, the most important aquifer system in west-central Missouri is the Cambrian-Ordovician suite of dolomite and sandstone formations. Fresh water can be obtained in amounts as high as 1 mgd per well from these rocks in the southeastern two-thirds of the 18,000-sq-mi area. Other aquifers of importance to farmers and rural residents are the unconsolidated, glacially derived sand and gravel in the uplands near the Missouri River, buried valleys in Jackson and Saline Counties, sandstone of Pennsylvanian age on the Osage plains, limestone of Mississippian age on the Springfield plateau, and alluvial deposits in the major plateau stream valleys.

Without storage, flows of streams on the Osage plains and on the Salem plateau north of the Osage River are undependable as water-supply sources. On the other hand, many of the streams in the remainder of the area to the east and south have ample flow without storage. This flow is contributed in large part by the numerous perennial springs tapping the underground storage in limestone and dolomite on the Salem and Springfield plateaus.

Potable water derived from wells, springs, and streams in west-central Missouri is of the calcium bicarbonate type or of the calcium magnesium bicarbonate type. The limestone aquifer on the Springfield plateau has a high pollution potential owing to the ease with which pollutants can reach the saturated zone.

OHIO

High-yielding wells in west-central Ohio

Studies of the carbonate-rock aquifers in central and southwest Ohio by S. E. Norris and R. E. Fidler have defined a new area of high ground-water yield and also indicate a relationship, on a regional basis, between the quality of the ground water and areas of recharge and discharge.

Relatively high-yielding wells, whose specific capacities exceed 5 gpm per ft of drawdown, occur in an irregular area of about 1,000 sq mi in the west-central part of the State. This area represents the southern terminus of a high-yield area in northwest Ohio and is associated with the Cincinnati arch, a major structural feature.

A comparison of selected ground-water-quality characteristics with a map of the potentiometric surface, as determined from the deeper wells, indicates a relatively high percentage of reacting values of bicarbonate in water from wells drilled on the major divides in areas of ground-water recharge and progressively lower bicarbonate values from wells in the vicinity of the principal streams in areas of ground-water discharge. When completed, the study will indicate the availability of large ground-water supplies in an important economic area of the State and will permit reasonable predictions of ground-water quality in advance of drilling.

ROCKY MOUNTAIN REGION

Water resources studies in the Rocky Mountain region emphasize the quantity and chemical quality of water resources available for use and increasingly are concerned with chemical-quality degradation problems associated with water development. The principal undeveloped or partially developed water resource in the region is ground water, and some of the recent results of ground-water studies are reported below.

The effect of urbanization and development of land for housing sites is becoming of concern in many areas of the West. Typical undeveloped lands undergoing change to moderately dense recreation housing areas are the Pinetop-Lakeside area of southern Navajo County, Ariz., and the Rock Creek area of Montana. In each of these areas, ground water is utilized, and sewage is disposed of through individual septic tanks. Because the ground-water supply is under increasing demand, some danger exists of overdevelopment and pollution from septic-tank effluent. Pollution has not been detected in the Rock Creek area, but isolated instances of pollution were reported from the Pinetop-Lakeside area.

Concurrent with increasing urban and industrial development is a need for additional water supplies. Recently drilled wells near McCoy, Colo., tapped a cavernous limestone aquifer under sufficient artesian head to flow at the surface. The largest flow is about 9,000 gpm, but the dissolved-solids concentration ranges from 700 to 4,600 mg/l. Test drilling near Buena Vista and Westcliffe, Colo., confirmed earlier geophysical work and proved an areally extensive aquifer that is locally 4,000 to 6,700 ft in thickness. Well yields of 500 gpm or more were obtained.

In contrast, the presence of ground water creates a potential local water-interference problem in the mining of oil shale in western Colorado. The Mahogany ledge oil-shale zone in the Piceance Creek basin is a moderately permeable aquifer, and yields of some test wells average 350 gpm and are as much as 1,000 gpm.

Regional studies in Oklahoma and Kansas showed that near-surface aquifers are extensively used for water supplies but that additional supplies can be developed from both surficial deposits and deeply buried bedrock aquifers. In southwest Oklahoma, well yields range from 50 to 1,500 gpm and the dissolved-solids concentrations range from 500 to 2,500 mg/l, but near the Wichita Mountains a high fluoride content in water developed from a limestone aquifer is a deterrent to use for public supply. In the middle Arkansas, Verdigris, and Neosho River basins of Oklahoma and Kansas, large quantities of good quality water are available in deep bedrock aquifers to supplement the more completely developed near-surface aquifers in surficial deposits. In contrast, much of the area of the Clinton quadrangle in west-central Oklahoma is underlain by rock units that yield limited amounts of water of poor chemical quality. The Ogallala Formation in the panhandle region of western Oklahoma is

extensively developed, and water levels are declining at a rate of 1 to 3 ft per yr.

Deeply buried and little-used bedrock aquifers in Kansas and Montana store large quantities of water useful for selective purposes. In central and southwest Kansas, deep sandstone aquifers are being developed to provide additional water supplies. Although the chemical quality is not as good as that in the extensively developed sand and gravel aquifers along the streams, water from the deeper aquifers is a significant addition to current ground-water development. Likewise, in eastern Montana, the deeply buried Madison Limestone is undeveloped and can supplement near-surface ground-water supplies with large quantities of water directly usable for irrigation and some industrial uses.

In northeastern Kansas, North Dakota, and South Dakota, a buried erosional surface and overlying glacial deposits are proving significant to water-resources development. Wells tapping glacial channel deposits in northeastern Kansas yield as much as 300 gpm of water that is usable for public supply. Test drilling in North Dakota and South Dakota, mainly in the Missouri River region, has defined glacial channel- and blanket-outwash deposits that yield from 25 gpm to more than 250 gpm to wells. The chemical quality of the water is good enough for the water to be used for public supplies.

ARIZONA

Ground-water resources in southern Navajo County

Studies by L. J. Mann indicated that the water supply in the Pinetop-Lakeside area of southern Navajo County, Ariz., is pumped from basalt flows of Tertiary to Quaternary age and from sandstone beds of Cretaceous age. The two units form a multiple-aquifer system, and wells tapping it generally yield from 50 to 200 gpm at depths of less than 300 ft. The water generally is of good chemical quality and contains less than 300 mg/l of dissolved solids; isolated instances of pollution from septic-tank effluent have been reported. Recharge from precipitation probably is sufficient to sustain the present rate of ground-water withdrawal. However, flows from several large springs have decreased as much as 50 percent, and a few springs have ceased to flow.

The main aquifer in southern Navajo County, the Coconino Sandstone of Permian age, is not yet extensively developed in the Pinetop-Lakeside area. The top of the aquifer is about 600 to 800 ft below land surface near Pinetop and Lakeside. Although the potential yield of the Coconino to an individual well is more than 300 gpm, large concentrations of iron in the water may limit its development.

COLORADO

Water levels decline in Black Squirrel Creek basin

D. L. Bingham and J. M. Klein reported that, since 1964, ground-water levels have declined as much as 35 ft—about 35 percent of the saturated thickness—near Ellicott, and 10 ft in a surrounding 18-sq-mi area of the upper Black Squirrel Creek basin in El Paso County, Colo. General declines in the area from 1955 to 1964 were from 2 to 7 ft; the declines resulted from withdrawals by pumping. Water withdrawn from eight municipal wells is conveyed out of the basin. In 1971, the total volume of water withdrawn by pumping was 13,500 acre-ft. Of this amount, 3,500 acre-ft was withdrawn by the eight municipal wells.

Large quantities of slightly to moderately saline water yielded by wells near McCoy

According to E. R. Hampton, four wells near McCoy, Colo., were reported to have flows of 9,400 gpm, 7,500 gpm, 650 gpm, and 10 gpm; the large flows have attracted widespread attention. Additional large water supplies as indicated by the wells, if of suitable quality, would add significantly to the water-resource base of the area. A compilation of readily available information and an aerial photoreconnaissance geologic map indicate that the wells tap the Leadville Limestone of Mississippian age, which is known to be cavernous at many localities. The Leadville Limestone in the area probably is less than 100 ft thick. Analyses of water from the wells show that the dissolved-solids concentration ranges from about 700 to 4,600 mg/l. The dissolved-solids concentrations in the water increase downdip, and water containing less than 1,000 mg/l probably occupies only a few square miles of the aquifer.

Traveltime and transportation loss of reservoir releases for the upper Arkansas River

The time of travel and transportation losses of reservoir releases for the Arkansas River from Twin Lakes Reservoir to the Colorado Canal headgate, a distance of 175 mi, were determined by R. K. Livingston. Transportation losses range from 15 to 90 cfs depending on antecedent riverflow, release discharge and duration, and month of the year. In general, these water losses exceed the approximately 12-percent loss currently charged against reservoir releases on the Arkansas River.

Thickness of upper Arkansas River basin valley-fill deposits

Data obtained by L. A. Hershey and P. A. Emery in the upper Arkansas River basin verify indications previously obtained through earth resistivity surveys that large ground-water reservoirs underlie areas near Buena Vista and Westcliffe, Colo. The deposits near Buena Vista may be as much as 4,000 ft thick and those near Westcliffe may be 6,700 ft thick. Two recently drilled test wells show that the deposits are water bearing and that yields of 500 gpm or more are obtainable from production wells drilled to depths of 1,000 ft or more.

Mahogany ledge zone in the Green River Formation, Piceance Creek basin, defined as an aquifer

F. A. Welder and J. E. Weir, Jr., reported that the Mahogany ledge oil-shale zone of the Green River Formation in the Piceance Creek basin in northwestern Colorado is, at some places, an aquifer rather than an aquiclude. This discovery is based on data from 13 exploratory holes drilled by private companies. Specific conductance of the water ranged from about 600 to 37,000 μmhos/cm. Transmissivity ranged from about 200 to more than 20,000 gpd per ft. Compressed air was used to pump the exploratory holes; some of the exploratory wells yielded more than 1,000 gpm, and the average yield was about 350 gpm.

KANSAS

Effects of irrigation development in central western Kansas

A recent study of ground water in Greeley, Wichita, and Wallace Counties, Kans., showed that the number of irrigation wells in the counties has increased from 100 to 1,400 in the past 20 yr. E. D. Jenkins (USGS), S. E. Slagle (USGS), and E. C. Weakly (Kansas Geol. Survey) reported that water levels have declined more than 30 ft in those parts of the counties where wells are concentrated and where ground-water withdrawals far exceed natural recharge. The study also has shown that water-level declines are minor in parts of the counties where there is little or no pumping.

Buried stream valley located in northeastern Kansas

A major preglacial buried stream valley eroded into bedrock of Late Pennsylvanian and Early Permian age has been mapped by J. R. Ward (Kansas Geol. Survey). In Nemaha County, the buried valley trends easterly from south of Centralia to Wetmore. Several buried tributary channels, which are also cut into bedrock, join the major valley at its base level. The buried valley is filled by glacial deposits that are as much as 380 ft thick. The deposits consist primarily of two tills of Kansan age which are separated locally by glacial outwash and underlain by lacustrine and glacial outwash deposits.

Ground water in the glacial deposits generally is unconfined, but artesian conditions exist locally. Yields of wells in the unconsolidated deposits range from less than 1 gpm to as much as 300 gpm. The water commonly is hard to very hard and is of the calcium bicarbonate type. However, water pumped from deep wells open to the basal part of the glacial deposits or to the underlying bedrock may contain sulfate concentrations greater than is generally recommended for drinking water (250 mg/l). The sulfate in the water probably has been derived from thin layers of gypsum in the Lower Permian bedrock. Hydraulic connection between the bedrock and the deeper part of the buried valleys allows water high in sulfate to move from the bedrock into the glacial deposits.

Test drilling aids irrigation development in central western Kansas

Data from exploratory drilling during the summer and fall of 1971 showed the areal extent and thickness of the water-yielding unconsolidated surficial deposits of sand and gravel in Scott and Lane Counties, Kans. Delineation of the aquifer, of Tertiary and Quaternary age, will aid irrigators and well drillers in planning future development of the ground-water resource. E. D. Gutentag and L. E. Stullken reported that ground-water withdrawal for irrigation has caused a significant depletion of ground-water storage in part of western Scott County. In such areas, where the unconsolidated aquifer is heavily pumped, the test drilling indicated that it may be feasible to obtain supplemental irrigation water from wells tapping a deeper bedrock aquifer of Cretaceous age.

Availability of water from Lower Cretaceous rocks

K. M. Keene (Kansas Geol. Survey) reported that water use from sandstone aquifers of Early Cretaceous age is being increased in central and southwestern Kansas to supplement ground-water supplies obtained from shallower, unconsolidated aquifers. Recently prepared maps indicated that the bedrock aquifer is within 500 ft of land surface in an area of more than 11,000 sq mi and that it contains water with a dissolved-solids concentration less than 1,000 mg/l.

MONTANA

Quality of water in the Rock Creek valley

Much of the range and pasture land in the Rock Creek valley is being subdivided and sold for small-acreage home sites. This change in land use has caused concern that the effluent from septic tanks may contaminate the ground water, which may in turn contaminate the stream.

A study by A. J. Boettcher indicated that nutrients contained in sewage effluent remain at low levels in the ground water and, at the present time, the effluent poses little threat to the stream. Both ground and surface waters contain less than 10 mg/l nitrite plus nitrite as nitrogen, and the concentration of dissolved solids is less than 250 mg/l.

Ground water in eastern Montana

Water in the Madison Limestone and associated rocks of Mississippian age in eastern Montana remains undeveloped because of the cost of drilling. A study by W. B. Hopkins of data from oil-test holes has roughly determined the depth to the aquifer, its potentiometric surface, and the chemical quality of the water.

The Madison Limestone is exposed in the mountains on the west and southwest margins of the area; the depth to the formation increases to more than 8,000 ft in the northeastern

part of the State. Throughout most of the area, the water is under sufficient artesian pressure to flow at land surface. Flows from wells that produce water for secondary recovery of oil in southeastern Montana average more than 900 gpm. South of the Yellowstone River and west of Musselshell County, the water is highly mineralized calcium sulfate type but is usable for irrigation and for some industrial processes. In the northeastern part of the State, the water is highly concentrated sodium chloride brine, containing as much as 325,000 mg/l dissolved solids.

Aquifer characteristics in southeastern Montana

W. R. Miller and W. B. Hopkins found significant variations in transmissivity among the five major aquifers in the Powder River area. Transmissivity of the alluvium along the Powder River is as much as 30,000 sq ft per day compared to the Fort Union Formation of Paleocene age where the greatest measured transmissivity is 100 sq ft per day. Transmissivity of the upper Hell Creek Formation and the Fox Hills–basal Hell Creek aquifer of Cretaceous age ranges from 100 to 400 sq ft per day. Data from three wells producing water from the Madison Limestone of Mississippian age indicated that the transmissivity is greater than 12,000 sq ft per day.

NORTH DAKOTA

Buried valleys in central southern North Dakota

C. A. Armstrong reported that test drilling outlined an eastward-trending buried valley, which is as much as 446 ft deep, near Strasburg, Emmons County. The trend and gradient of the buried valley indicate that it is part of a drainage system that predates the Missouri River drainage system in North Dakota. The buried valley was filled principally with clayey silts but does contain scattered sand and gravel aquifers. Some of the aquifers may yield as much as 75 gpm to a well, but most aquifers probably will yield less than 25 gpm.

P. G. Randich reported that test drilling west of the Missouri River, in eastern Grand County and northern Sioux County, revealed a buried valley more than 300 ft deep. The valley intersects and extends beneath modern drainage courses such as the Heart and Cannonball Rivers. In places, the valley contains more than 100 ft of saturated sand and gravel, but the deposits are discontinuous. The deposits are aquifers which, in places, are hydraulically connected with overlying alluvial aquifers. The chemical quality of water in the lower part of the buried-valley deposit closely resembles that of adjacent and underlying bedrock formations; the water is a sodium bicarbonate sulfate type that contains from 2,000 mg/l to 2,500 mg/l of dissolved solids. However, better quality water occurs in the upper part of the buried-valley deposit; the water is a sodium calcium bicarbonate type and the dissolved-solids concentration ranges from 700 to 1,200 mg/l.

Subsurface exploration defines aquifers in central eastern North Dakota

According to J. S. Downey, subsurface exploration in Griggs and Steele Counties during 1971 disclosed the presence of a significant thickness of saturated sand and gravel over a large part of both counties. The Spiritwood, McVille, and Page-Galesburg aquifers have been identified. Large areas of these aquifers are capable of supporting well yields greater than 250 gpm. Water from these aquifers is of fair to good quality. Dissolved solids are generally below 1,000 mg/l.

Aquifer tests in Cavalier and Pembina Counties

According to R. D. Hutchinson, an aquifer test on the Munich aquifer, located in southwestern Cavalier County, showed a transmissivity of 4,200 sq ft per day and a storage coefficient of about 4×10^{-4}. A production well was pumped continuously for 4 days at 225 gpm. Although the aquifer is believed to be a narrow valley-fill deposit, no boundary effects were noted during the test. The dissolved-solids concentration in the water was about 1,750 mg/l.

A test was conducted on the Icelandic Park aquifer in central Pembina County. The test data are still being analyzed, but a transmissivity of about 200 to 450 sq ft per day seems reasonable. The aquifer is a spit-bar deposit about 20 mi long by 4 mi wide that averages about 40 ft in thickness. The deposit consists mostly of very fine to fine quartz sand. The maximum well yield from the aquifer is about 50 gpm. The dissolved-solids concentration in the water is about 200 mg/l.

Glacial-melt-water channels in central western North Dakota

R. L. Klausing reported that test drilling in Dunn County in central western North Dakota revealed that several glacial-melt-water channels had eroded into partially consolidated beds of silt, clay, fine sand, and lignite of Paleocene age. Glacial outwash of Quaternary age is the main deposit filling the channels and is a potential aquifer. The outwash is dominantly sand, gravel, and silt. The largest of these channels extends eastward from the vicinity of Killdeer to near Dunn Center. From this point the channel extends southward into Stark County. The channel ranges in width from about a quarter of a mile to a mile and contains saturated sand deposits that may be as much as 100 ft thick.

OKLAHOMA

Appraisal of ground-water supplies in southwestern Oklahoma

According to J. S. Havens, hydrologic reconnaissance of the Lawton 1° by 2° quadrangle (an area of about 6,200 sq mi) in southwestern Oklahoma showed that several geologic units are aquifers. Wells in alluvium and terraced alluvial deposits along the Red River in the western part of the quadrangle yield as

much as 1,400 gpm of water that contains about 2,000 to 2,500 mg/l of sulfate, whereas wells along tributaries to the Red River have smaller yields of water and lower sulfate concentrations. Eastward along the Red River, wells tapping similar deposits yield as much as 600 gpm of water that contains about 500 to 1,000 mg/l dissolved solids and that is moderately hard (120 to 180 mg/l), and wells along tributaries again have smaller yields with a lower mineral concentration. In the extreme northeastern part of the area, wells in the Rush Springs Sandstone (Permian) yield 50 to 300 gpm; the water is suitable for irrigation and domestic supplies and generally contains less than 500 mg/l of dissolved solids. In the western part of the area, the Blaine Formation and Dog Creek Shale (Permian) yield 100 to 1,500 gpm; although this water has a 2,000 mg/l to 3,000 mg/l sulfate content, it is extensively used for irrigation. Permian red beds in the eastern half of the quadrangle yield little water, and inhabitants of the area rely on cisterns, ponds, or rural water districts for domestic supplies.

Limestones of the Arbuckle Group (Cambrian and Ordovician) north, south, and east of the Wichita Mountains yield as much as 600 gpm. However, water from these wells has a fluoride content ranging from 1.7 mg/l on the south side of the mountains to as much as 37 mg/l on the north side. A possible source of the fluoride is the Post Oak Conglomerate Member of the Wichita Formation (Permian), which consists largely of igneous rock detritus derived from the granite, rhyolite, and gabbro that make up the Wichita Mountains. Two to four miles north of the mountains, highly folded and faulted rocks of the Arbuckle Group form a northwesterly-trending range of hills; here, artesian wells and springs yield as much as 100 gpm. The fluoride concentration of water in this area ranges from 0.3 to 2.5 mg/l. Although this area has potential as a source of low-fluoride water, the complex geologic structure is a deterrent to ground-water exploration.

Availability of ground water in the middle Arkansas, Verdigris, and Neosho River basins, Oklahoma and Kansas

Analyses of data from northeastern Oklahoma and southeastern Kansas (an area of about 44,400 sq mi) by R. B. Morton and S. W. Fader showed that the region has substantial ground-water resources.

In the middle Arkansas basin water-bearing alluvium and terraced alluvial deposits (Tertiary to Holocene) range in thickness from 10 to 350 ft. Well yields from these aquifers range from less than 100 gpm to as much as 4,000 gpm, but typical yields are about 1,200 gpm. The chemical quality of water from these aquifers is generally good. The amount of water stored in the unconsolidated aquifers is estimated at 85 million acre-ft; however, only about 50 percent of this water is economically recoverable. Withdrawals in recent years, mainly for irrigation, have been about 260,000 acre-ft annually, and annual recharge is estimated at about 2 million acre-ft.

In the middle Arkansas basin, wells completed in bedrock that consists mainly of shale, siltstone, and sandstone (Pennsylvanian to Cretaceous) generally yield less than 10 gpm of fair to good quality water. Deeper wells would provide greater yields but the water probably would be more highly mineralized. The only significant bedrock aquifer in the basin is the Sumner Group (Permian). Wells completed in this aquifer reportedly yield as much as 300 gpm.

In the Verdigris River basin, bedrock is mainly shale, siltstone, and sandstone. These rocks generally yield less than 10 gpm to wells. Water quality generally is good although some contamination by oil-field brines occurs locally. The amount of water stored in bedrock is estimated at about 1 million acre-ft, most of which is not economically recoverable.

Deposits of gravel, sand, silt, and clay (Pleistocene to Holocene) in the Verdigris basin range in thickness from 10 to 60 ft in major stream valleys. Wells in these deposits reportedly yield as much as 500 gpm but the average yield is about 20 gpm. The chemical quality of water is generally good although excessive hardness is a troublesome characteristic. The amount of water stored is estimated at about 1 million acre-ft but less than one-half is economically recoverable. Recharge is about 161,000 acre-ft annually and in 1968 about 4,200 acre-ft was withdrawn.

In the Neosho River basin bedrock is mainly shale, siltstone, sandstone, and cherty limestone (Mississippian and Pennsylvanian). Wells in the shale, siltstone, and sandstone units generally yield less than 10 gpm of fair to good quality water. Wells in the cherty limestone generally yield less than 10 gpm although, dependent on the degree of local fracturing, some wells yield several hundred gallons per minute. The eastern part of the basin is underlain by sandy dolomite (Ordovician) at depths of a few hundred feet to as much as 1,200 ft; wells in these rocks yield as much as 1,000 gpm but the average yield is about 200 gpm. The chemical quality of water from the sandy dolomite is good in the eastern part of the basin but the water becomes saline downdip toward the west. The amount of water stored in the upper 300 ft of bedrock in the basin is estimated at 69 million acre-ft. In 1968, about 5,500 acre-ft was withdrawn from the dolomite aquifers, mainly for municipal and industrial uses.

Overlying the bedrock in places in the Neosho basin, unconsolidated alluvium, ranging in thickness from 10 to 60 ft, reportedly yields 100 gpm to wells, but larger yields may be available locally. The average yield is about 30 gpm. Although very hard, the water is generally of good quality. The amount of water stored in the alluvial aquifers is estimated at 775,000 acre-ft but a large part is not economically recoverable. The annual rate of recharge is estimated at 226,000 acre-ft and, in 1968, about 2,500 acre-ft was withdrawn.

Appraisal of ground-water supplies in west-central Oklahoma

Data collected as part of a hydrologic reconnaissance of the Clinton 1° by 2° quadrangle (an area of about 7,800 sq mi) by

J. E. Carr and D. L. Bergman showed that about one-half of the area is underlain by geologic units that are significant aquifers. The remaining one-half of the quadrangle is underlain by gypsiferous shale, siltstone, and fine-grained sandstone that yield only limited amounts of water containing excessive amounts of dissolved solids.

Wells in the Rush Springs Sandstone (Permian) yield as much as 700 gpm north of the Washita River and as much as 200 gpm south of the river. The chemical quality of water from the Rush Springs is generally good except where it is overlain by the Cloud Chief Formation. High-sulfate water in the Cloud Chief mixes with and degrades the quality of native water in the Rush Springs. Wells in alluvium along the Washita River in Custer and Roger Mills Counties yield as much as 1,200 gpm; elsewhere alluvium and terraced alluvial deposits yield as much as 500 gpm. Water from the terraced deposits is not as highly mineralized as that from alluvium at the stream channel level, but water from either source is suitable for irrigation. The Elk City Member of the Quartermaster Formation (Permian) in Washita and Beckham Counties yields as much as 100 gpm of water of good quality. The Ogallala Formation (Tertiary) yields as much as 300 gpm locally. Water from the Ogallala is suitable for irrigation and municipal use.

Water levels in the Ogallala Formation in the Oklahoma Panhandle

D. L. Hart, Jr., and G. L. Hoffman reported that water levels in the Ogallala Formation have continued to decline at a rate of 1 to 3 ft per yr in heavily pumped areas in the Oklahoma Panhandle. In a few areas, water levels declined as much as 10 ft during the 1971 agricultural season. The maximum cumulative decline since 1966 has been about 49 ft. Approximately 1,850 irrigation wells now tap the Ogallala aquifer although the rate of well completions has decreased in the past year. The greatest concentrations of wells is in the vicinity of Guymon and Goodwell in Texas County and Boise City and Felt in Cimarron County. These areas are also the areas of greatest water-level declines. Most of the recent well development has been in north-central and northwest Texas County. Accelerated rates of water-level declines can be expected in these areas as pumpage increases. Water levels outside of the heavily pumped areas have shown little change in the past few years.

SOUTH DAKOTA

Extensive glacial aquifer in Brown and Marshall Counties

N. C. Koch and W. L. Bradford reported that a program of test drilling and data from a well inventory indicated that an aquifer underlies about 1,200 sq mi in the eastern two-thirds of Brown County and most of the Coteau des Praires, a range of low hills in Marshall County. In Brown County the aquifer is generally within 30 ft of land surface and ranges from 2 to 50 ft in thickness. In the Coteau des Praires, the aquifer underlies an area of about 400 sq mi. The thickness ranges from 4 to 50 ft, and wells tap the complete aquifer at depths ranging from 176 to 464 ft below land surface. Water in the aquifer may be under artesian or water-table conditions, and water levels in wells range from 156 to 350 ft below land surface. Springs discharge from the aquifer along the sides of the Coteau.

Three underdeveloped aquifers can supply irrigation or municipal water in southeastern South Dakota

An appraisal of the water resources of Charles Mix and Douglas Counties, southeastern South Dakota, by Jack Kume showed that the Choteau, Tower, and Greenwood aquifers can supply additional irrigation and municipal water. The three aquifers underlie a total of about 208,000 acres, store about 2,430,000 acre-ft of water, and will yield 500 gpm or more to properly constructed wells. The dissolved-solids content of the water averages about 1,700 mg/l and ranges from 1,000 mg/l to 3,000 mg/l. The water has a hardness in excess of 180 mg/l. The Choteau aquifer, which has the greatest potential, is the most extensively developed; it supplies water to 13 irrigation and five municipal wells. The Tower and Greenwood aquifers have not been developed.

UTAH

Uinta Basin aquifers are mainly semiconsolidated to consolidated sedimentary rocks

Preliminary studies by J. W. Hood, F. K. Fields, and D. B. Adams suggested that most of the ground-water aquifers in the Uinta Basin are saturated sedimentary rocks of ages ranging from the Uinta Mountain Group of Precambrian age to the Browns Park Formation of late Tertiary age. Quaternary gravel and sand underlying stream valleys and terraces appear to act mainly as a transfer medium in the aquifer recharge and discharge processes. Although most of the water probably is stored as interstitial water in formations of moderate to low permeability, large yields are obtained from springs that discharge mainly from rocks of Paleozoic age near the base of the Uinta Mountains. Records of oil test wells and oil wells near Vernal show that fresh or slightly saline water is present in both the Paleozoic aquifers and the Wasatch Formation of early Tertiary age at depths of 4,000 to 5,000 ft.

Preliminary work by Donald Price and L. L. Miller in the southern Uinta Basin indicated that most of the ground water in this predominantly arid region is saline. This part of the basin is directly underlain by several thousand feet of Tertiary lakebed deposits that include large amounts of soluble salts. The deposits yield fresh water to numerous small high-altitude springs but generally yield saline water below an altitude of about 7,000 ft.

Water resources of Dinosaur National Monument

C. T. Sumsion reported that ground water is available from sandstone and limestone aquifers in the lower areas of Dinosaur National Monument; higher areas are well drained and dry. Water use, all from wells, during 1970 was estimated to be 15 million gal. The chemical quality of water from wells and springs is generally good.

PACIFIC COAST REGION

Among the many activities of the USGS water-resources program in the Pacific coast region, a few were given special attention during the year.

Special efforts were made to rapidly obtain comprehensive hydrologic data of a transportation corridor in Alaska—the route selected for the proposed oil pipeline from the Prudhoe Bay oil field to the ice-free port of Valdez. New gaging stations for hydrologic determinations were installed and old ones were reactivated. Studies were made of the historic and probable future stability of river channels crossed by the transportation corridor. Other studies were concerned with establishing chemical quality and biologic viability of streams to form a preconstruction baseline of information. A beginning was made in the evaluation of ground water as both a resource and a hazard along the corridor.

In Hawaii a project was implemented, as part of a nationwide program, to study geologic and hydrologic conditions related to waste-water disposal. Preliminary activity involved a compilation of essential data regarding places and methods of waste-water disposal on the islands.

Most of the known geothermal areas in the United States are in the Pacific coast region; therefore, the program of investigation of geothermal resources centers in that region. This new program has been designed to use hydrologic talents in conjunction with other special skills furnished by scientists and technicians of the USGS in a coordinated effort to understand the geologic and hydrologic settings and behaviors of geothermal areas. Understanding and quantification of the resource are necessary before intensive development of geothermal energy can proceed in an orderly and effective way.

Meanwhile, ongoing programs such as the San Francisco Bay region environment and resources planning study, collection and analyses of data on surface and ground water and on water quality, research projects, and resource-appraisal studies continued.

CALIFORNIA

High artesian head in Death Valley National Monument

At the north end of Tucki Mountain a 702-ft-deep test hole was drilled through alluvial-fan deposits and into sedimentary rocks of Paleozoic age. Water was encountered under an artesian head of several hundred feet. According to G. A. Miller, the aquifer system, which consists mostly of beds of limestone and dolomite, is of very low permeability. The water contains about 3,000 mg/l of dissolved solids.

Ground-water levels up in Santa Margarita River and San Luis Rey River watersheds

J. A. Moreland reported that approximately 160 wells were measured in the Santa Margarita River and the San Luis Rey River watersheds in the fall of 1971. Ground-water levels were, in general, higher than they were during the initial well canvas made in 1966 through 1968. Water samples from over 50 wells were collected and analyzed. Ground-water quality continues to deteriorate throughout most of the area. A transmissivity map for the lower part of the San Luis Rey River valley shows that transmissivities range from about 1,000 gpd per ft in the older alluvium to more than 100,000 gpd per ft in the younger alluvium.

Artificial recharge in the Irvine area

An evaluation of potential recharge sites in the Irvine area by J. A. Singer indicated that large-scale spreading of water is not possible. Auger holes were drilled along the mountain front and only deposits having low permeability were encountered. The study also indicated that the Irvine ground-water basin is in hydrologic continuity with that of the rest of Orange County.

HAWAII

Water resources of the island of Hawaii

Average rainfall on the 4,000-sq-mi volcanic island of Hawaii amounts to about 10 bgd, but perennial streams enter the ocean along only a little more than 10 percent of the total coastline of the island, according to George Yamanaga and D. A. Davis. The perennial flow is supplied by persistent rainfall on parts of the northeastern slope of the island and by the high-level ground-water discharge from dike-impounded and perched reservoirs intersected by stream valleys. The largest flow into the ocean is from a great body of ground water near sea level, which floats on sea water in permeable lavas and discharges at sea level along the rocky shores. Because of mixing with sea water, most of the flow at the shore is brackish or saline. The greatest flows are on the rainy eastern side of the island. In the drier western part, effects of mixing may cause the water to be brackish at sites several miles inland from the shore.

Basal ground water in the Pearl Harbor area

From about 1910 to 1960, there were few changes in the location of wells or the amount of pumpage in the Pearl Harbor area. Between 1960 and 1971, there has been a rapid

urbanization of the area. Large pumping plants that were formerly used for irrigation of sugarcane have been abandoned, and new well fields have been developed to supply the water for urban and industrial growth. R. H. Dale found that within the last few years there has been a significant change in salinity and water levels in the area subject to the change in pumping rates. It appears that changes in salinity lag behind the changes in pumping rates by several years.

IDAHO

Leakage from Blackfoot Reservoir, southeastern Idaho

In a study designed to determine the amount of water leaking out of Blackfoot Reservoir (Columbia River drainage) into the Bear River basin (Great Basin drainage), N. P. Dion obtained preliminary, unadjusted values of 25 to 43 cfs. This effort represents the first attempt to determine quantitatively the amount of leakage from the reservoir, which is situated almost entirely on fractured and faulted basalt.

Hydrology of the upper Salmon River, Idaho

The upper 1,800 sq mi of the Salmon River drainage was studied by W. W. Emmett to evaluate potential degradation of that primitive area by mineral exploration, mining, and other land uses. Results of the study, interrelating the geomorphology and hydrology, indicated that most of the area has not yet felt the impact of man. The data are indicative of baseline characteristics. Runoff is characterized by a bankfull discharge Q_B (in cubic feet per second) having a frequency of occurrence of 1.5 yr and a magnitude related to drainage area DA (in square miles) of $Q_B=25DA^{0.7}$. The average annual discharge has a flow duration of 25 percent of time and ratios of depth and discharge to bankfull values of 0.54 and 0.24, respectively. The 50-yr flood has ratios of depth and discharge to bankfull values of 1.65 and 3.35, respectively.

Chemical analyses indicate that generally water quality far exceeds drinking-water standards. The total of dissolved heavy metals and trace elements generally do not exceed 1.0 mg/l. At the exit from the study area, dissolved solids are about 65 mg/l at high flow (5-yr flood) and 100 mg/l at low flow (average annual discharge).

On a yearly basis, the total dissolved load is about 10 times greater than the suspended-sediment load. At the exit from the study area, the suspended-sediment load is slightly greater than the dissolved load at high flow but is more than 10 times less at low flow. At high flow, the bedload may be 50 times greater than the suspended load, but at low flow, very little material is transported as bedload.

Inflow to Boise River between Lucky Peak Dam and the river's mouth

C. A. Thomas and K. L. Dyer reported that, of the total of 1,000 cfs inflow in the 64-mi reach between Lucky Peak Dam and the mouth of the Boise River, 23 cfs entered in the upper 12 mi, 107 cfs entered in the next 21 mi, and nearly 830 cfs entered in the lower 31 mi of the reach. More than half, or about 550 cfs, was contributed by five drainage channels—Fifteenmile Creek, Mason Creek, Hartley Drain, Indian Creek, and Dixie Slough. Specific conductance of the Boise River increased from 93 μmhos/cm at the dam to 711 μmhos/cm at the mouth of the river. The specific conductance of most drains ranged between 400 and 900 μmhos/cm. The maximum measured was 1,110 μmhos/cm. Total phosphorus increased from 0.07 mg/l at the dam to 0.49 mg/l at the river's mouth, whereas total nitrogen increased from 0.78 mg/l to 3.6 mg/l in the same reach.

NEVADA

Bathymetric surveys completed

F. E. Rush reported that bathymetric surveys were made in the summer of 1971 on 10 lakes and reservoirs of northwestern Nevada. The lakes and reservoirs and their volumes are: Big Washoe Lake, 30,000 acre-ft; Little Washoe Lake, 500 acre-ft (Rush, 1972a); Big Soda Lake, 35,000 acre-ft; Little Soda Lake, 770 acre-ft (Rush 1972b); Topaz Lake, 126,000 acre-ft (Rush and Hill, 1972); Rye Patch Reservoir, 171,000 acre-ft; Upper Pitt-Taylor Reservoir, 24,200 acre-ft; Lower Pitt-Taylor Reservoir, 22,200 acre-ft (Rush and Rice, 1972); Marlette Lake, 11,800 acre-ft; and Spooner Lake, 1,410 acre-ft (Rush and others, 1972).

Water resources of the Truckee River basin

A 2,280-sq-mi area of the Truckee River basin, excluding the Lake Tahoe basin, is dominated hydrologically by the Truckee River, Pyramid Lake (into which the river empties), and the Truckee Canal (which carries about half of the river flow out of the basin). According to A. S. Van Denburgh, runoff at the mountain front and potential ground-water recharge each total about 100,000 acre-ft per yr and about 5 million acre-ft of ground water is stored in the upper 100 ft of saturated valley fill.

In 1969, 44,000 acre-ft of water was withdrawn for domestic, public-supply, and industrial uses. About 70 percent of the water was withdrawn from the Truckee River and Hunter Creek and the remainder was pumped from wells. Withdrawals for irrigation came almost entirely from streams.

Water of suitable quality for domestic use and public supply is available in all the valleys studied, but problem areas do exist. The poorest quality water from wells occurs northeast of Fernley and Wadsworth, in the Nixon area, northwest of Pyramid Lake, in the central and eastern parts of the Winnemucca Lake valley, and in parts of Truckee Meadows. For agricultural use, ground water downstream from Wadsworth is least suitable, whereas most water in the other valleys

is acceptable. The quality of the surface water in nearly all streams is suitable for domestic, public-supply, and agricultural uses.

OREGON

Productive aquifers in Corvallis-Albany area

Sand and gravel deposits of the main valley plain are the most productive aquifers in the Corvallis-Albany area. Recent studies by F. J. Frank indicated that only these alluvial aquifers are capable of supporting large-scale development of ground-water supplies. In most parts of the alluvial valley, wells that will produce several hundred gallons per minute of good quality water can be developed.

In contrast, wells in volcanic and sedimentary rocks in the adjacent uplands are adequate only for domestic supplies. Locally, water of poor chemical quality occurs in sedimentary rocks that underlie alluvial deposits in the main valley plain.

WASHINGTON

Regional ground-water flow at the Hanford Reservation

A. M. La Sala, Jr., G. C. Doty, and F. J. Pearson, Jr., investigated the regional ground-water flow in the vicinity of the AEC Hanford Reservation in connection with a proposal to store high-level radioactive wastes at depths of 3,000 to 4,000 ft in the basalt of the Columbia River Group. Flow through the ground-water systems was studied on the basis of ground-water heads measured in wells, chemical characteristics of the ground water, and its isotope contents (tritium, carbon-14, and stable carbon isotopes). The principal water-bearing zones in the basaltic rocks lie between major flows where rubble, scoria, fractured basalt, or sediments occur. The hydraulic conductivity is therefore greatest in a direction concordant with the bedding. Nevertheless, the cross-bed hydraulic conductivity is large enough, so that the basalt has been significantly, although unintentionally, recharged by applied irrigation water. Ground water discharges to the major streams, of which the Columbia River is the largest. The oldest ground water found in the region (30,000 to more than 40,000 yr B.P.) is near the Columbia River.

Hydrologic conditions in the Ellensburg Formation and Yakima Basalt

The lower Yakima valley is formed by a syncline underlain by the Ellensburg Formation resting uncomformably on the Yakima Basalt. In the eastern part of the valley (Toppenish Creek basin) the upper part of the Ellensburg Formation has been reworked by the Yakima River. The resultant alluvium has an average permeability of about 5,000 to 10,000 gpd per sq ft for several tens of feet according to D. O. Gregg and R. J. Burt. The Ellensburg Formation itself has a lower transmissivity. Ground-water levels in wells tapping the formation rise 2 to 16 ft each summer in response to irrigation with surface water.

The average transmissivity of the basalt beneath the Ellensburg is about 200,000 gpd per ft and in places is as much as 1,000,000 gpd per ft. However, the natural-recharge potential is low and the storage coefficient is 1×10^{-4} or less, which results in significant drawdown in response to irrigation pumping. The potentiometric surface generally declined from 5 to 10 ft from January 1971 to January 1972.

Multiaquifer wells in eastern Washington

In order to obtain data on the relation between pumpage and water-level declines in multiaquifer wells—data not available from the usual irrigation wells in basalt—several test-observation wells have been drilled in eastern Washington, under the supervision of K. L. Walters. In one well, 750 ft deep, six aquifers were identified and isolated for individual water-level observations by means of a system of cement plugs, gravel backfill, and piezometric pipes. The composite depth to water before aquifer isolation ranged from 133 to 155 ft over a 2-month period. Immediately after isolation, water levels in the individual aquifers ranged from about 95 to almost 280 ft below land surface. Aquifers at different depths also have decidedly different patterns of response to local heavy pumpage.

Quality of water on Indian reservations

With isolated exceptions, the marine waters surrounding the Lummi Indian Reservation, Whatcom County, Wash., are of good sanitary quality. The fresh surface waters are free of undesirable concentrations of trace metals, pesticides, and herbicides. Only very low concentrations of DDD, DDE, and DDT have been detected in the fresh-water sediments, according to G. G. Parker, Jr., and D. R. Cline.

The ground water underlying the seaward end of the Lummi peninsula is fresh, but most of the ground water underlying the landward end of the peninsula is too saline for domestic use. Saline ground water apparently is relict sea water dating from Pleistocene time rather than modern ocean water drawn in by pumping.

D. A. Myers reported that water levels in wells on the Nisqually Indian Reservation in Thurston County, Wash., indicate a slight gradient toward the Nisqually River. However, the aquifer is confined by fluvial silt and clay in the river valley, and wells drilled there have produced artesian flows. The quality of the water is generally good except for the presence of undesirable concentrations of iron in some wells. These findings indicate that a proposed housing development for the Indians could be completed and probably not affect the purity of the water.

Residents of the Skokomish Indian Reservation and adjacent land, which includes the flood plain of the Skokomish

River near its mouth and low drift-plain uplands on the west, are supplied principally by ground water from shallow dug wells and from drilled wells, 30 to 60 ft deep, all tapping alluvial deposits. Water levels in the wells generally are within a few feet of land surface except that, on the flood plain, two wells 94 and about 100 ft deep provide flowing artesian water. According to Dee Molenaar, large supplies of ground water sought by Skokomish Indians for potential future industrial use possibly can be obtained from this artesian aquifer.

WORLDWIDE AND INTERREGIONAL STUDIES

Geohydrologic environmental studies

J. N. Payne completed maps showing maximum sand-unit thickness, estimated coefficients of transmissivity, and dissolved solids of water of the Carrizo Sand of Arkansas, Louisiana, and Texas and the Meridian Sand Member of the Tallahatta Formation of Mississippi. These maps show an excellent correlation between massive sand development, transmissivity, and the extent of flushing by fresh water of the Carrizo and Meridian. In some areas in southern Texas, where thick sands are extensively developed and hydrostatic head and transmissivity are high, fresh water extends to depths of 5,000 ft.

Chemical analyses of water from wells in the Carrizo Sand indicate that water in the southern Texas area is a calcium bicarbonate type at altitudes of about 1,000 ft below sea level and is a sodium bicarbonate type at altitudes from about 1,000 to more than 4,500 ft below sea level. In Arkansas, Louisiana, Mississippi, and eastern Texas the water from the Carrizo and Meridian is generally a sodium bicarbonate type.

Appraisal of icebergs as a water resource

W. F. Weeks (U.S. Army Cold Regions Research and Eng. Lab.) and W. J. Campbell (USGS) gave further consideration to the possibility of transporting large icebergs to arid regions where the icebergs could be used as sources of fresh water. The problem was considered in four main parts:

1. Location of a supply of icebergs: Only in the Antarctic are supplies of large tabular icebergs available. Data on size distribution of these icebergs indicate that icebergs of almost any desired size can readily be located.
2. Melting in transit: Although melting is quite significant, if a large iceberg can be towed there will still be ample ice when the iceberg arrives at its destination.
3. Power requirements: Currently available tugs are capable of towing quite large icebergs at slow velocities.
4. Economic feasibility: Calculations indicate that towing is economically feasible.

SPECIAL WATER-RESOURCES PROGRAMS

SALINE WATER

Brine movement through the Great Salt Lake causeway

According to K. M. Waddell and E. L. Bolke, time-of-travel studies, in conjunction with test holes drilled in a permeable rockfill causeway across the Great Salt Lake, Utah, facilitated the determination of hydraulic properties of the fill material. Computations indicated that during the fall of 1971, from 1,500 to 2,000 cfs of brine were moving from the south arm of the lake, through the causeway fill to the north arm of the lake.

Saline-water aquifer found beneath Sanibel Island

D. H. Boggess reported that a shallow artesian aquifer on Sanibel Island, Fla., occurs at a depth of about 30 ft below sea level. The aquifer contains water with chloride concentrations ranging from 2,250 to 30,900 mg/l. Water levels in the aquifer fluctuate in response to tidal loading and unloading effects, with tidal efficiencies ranging from about 50 to 75 percent.

Investigation of possible salt-water encroachment resulting from rediversion of Lake Moultrie

F. A. Johnson and S. J. Playton reported that a planned rediversion of Lake Moultrie discharge away from the Cooper River in South Carolina required an investigation of possible salt-water encroachment. A controlled discharge of 3,000 cfs, the proposed average after rediversion, was maintained from November 3–13, 1971. The preceding discharge was about 22,000 cfs. In addition to determining the effect of a 3,000-cfs discharge, it is anticipated that a three-dimensional mathematical model will be developed from the precise data collected. This model would define the effects of streams on the Cooper River estuary longitudinally, vertically, and laterally. The data-collection program was of a level of precision necessary to allow later development of a one-dimensional model of Clouter Creek and a three-dimensional model of the Cooper River. The models will enable USGS scientists to predict the results of future stresses on these systems accurately.

Some answers are already apparent from the collected data:

1. A sustained flow from Lake Moultrie of 3,000 cfs will probably be sufficient to keep salt water below the Cooper River entrance to the Durham Creek canal under normal tidal conditions. Just prior to the 3,000 cfs sustained-flow period, the salt-water wedge at high slack tide came to about mile 13.5, using a conductivity base of 125 μmhos as the delineation between salt water and

fresh water. The maximum measured salt-water penetration was to about mile 31.0 (about 2½ mi below the canal) measured at high slack tide November 9 and again November 12.

2. The leading edge of the wedge evidences a greater degree of stratification at high and medium fresh-water inflows than at low fresh-water inflows. The wedge at the beginning of the data-collection period was rather pronounced and ended abruptly. After 3 or 4 days of sustained low flow, the linear extent of high-tide penetration became relatively stable. The leading edge of the wedge became a diminution of well-mixed salinity in cross sections rather than a pronounced wedge effect. Also, the mixture extended over a much longer distance at low salt content than was the case with higher fresh-water inflows. The saline-water wedge section (400 to 125 μmhos) extended for about 6 mi, whereas it had been only 2 or 3 mi prior to the 3,000 cfs sustained flow.
3. The measured values of the investigated parameters remained fairly constant in absolute values at the same depth throughout the cross section. Neither DO nor pH showed much variation from saline to fresh water. At 9,300 μmhos and 16.5°C, DO was 7.3 ppm, and pH was 7.6; at 160 μmhos and 15.5°C, DO was 8.2 ppm, and pH was 7.2.
4. The tidal excursion of the wedge at 125 μmhos varied considerably. The tidal excursion at 3,300 μmhos was about 7 mi. Generally, there is less tidal excursion of the wedge at higher fresh-water inflows.
5. Any major change in the level of fresh-water inflows, whether an increase or decrease, will, if sustained, produce a fairly rapid change in the positioning of the wedge at slack tides for about 3 or 4 days. Then it becomes relatively stabilized.

DATA COORDINATION, ACQUISITION, AND STORAGE

Office of Water Data Coordination

A major element in the OWDC program in fiscal year 1972 was carrying out the second field-coordination effort since the beginning of the program. The scope was increased over that of the previous year to include acquisition of data on surface-water stage, streamflow, and quality, as contrasted with the previous coverage of only continuous or daily measurement of flow. Federal-agency plans for data acquisition through June 30, 1973, call for the discontinuance of 501 stage or streamflow stations and the activation of 289 new stations, a net decrease of 212 long-term stations in the period January 1, 1971, to June 30, 1973. Federal agencies reported plans for activation of 327 long-term surface-water quality stations and discontinuance of 117 stations, a net increase of 210 stations. The foregoing figures do not include increases planned at the headquarters level by the Environmental Protection Agency and the USGS. The former reported plans to initiate or intensify water-quality data acquisition at several thousand sites. The USGS reported plans to activate 18 new water-quality stations and intensify water-quality data acquisition at 91 existing stations in the Level I Accounting Element of the National Water Data Network. Regional plans were prepared for each of 21 water-resources regions and the report, "Summary of Plans for Acquisition of Surface-Water Data by Federal Agencies, Fiscal Year 1973," summarizes the regional reports.

Agencies were asked to list needs that were not being met or that they anticipated would not be met in fiscal year 1973. The agencies identified 581 sites at which stage or discharge data were needed and 409 sites at which water-quality data were desired. Agencies also were asked to supply, in narrative form, information on other unmet needs for water data. The need for additional streamflow, water-quality, and rainfall data for small watersheds, emphasized in the fiscal year 1972 summary report, appeared again, with additional agencies expressing such needs. The most critical need expressed was for expansion of the water-quality data base, both in terms of number of data-acquisition activities and of parameter coverage. A general need was expressed for additional data for urban areas and for lakes, ponds, reservoirs, and estuaries.

The summary also contained an appendix listing current activities in streamflow and quality of surface water for the Level I Accounting Element of the National Water Data Network. This is the first formal listing of such activities and marks the initiation of activities by the USGS to fully implement this element of the National Water Data Network.

The Federal Interagency Work Group on Hydrologic Data for Small Watersheds released their preliminary report, "Hydrologic Data Program for Small Waterheds, Part 1—Streamflow and Related Precipitation Data." The report contains an evaluation of the present data base, identification of deficiencies, and recommendations for a program to meet those deficiencies. The work group began activities to identify deficiencies in data on quality of surface water.

The surface-water stage and streamflow and water-quality sections of the "Catalog of Information on Water Data" were updated in conjunction with the field-coordination effort. Federal and non-Federal agencies were asked to revise their input to the catalog as of January 1, 1972.

A special meeting of the Federal Advisory Committee on Water Data was held to review and discuss the proposal of the Federal Interagency Water Data Handling Work Group to establish a National Water Data Exchange (NAWDEX). The Committee endorsed the concept and released the report of the work group, "Design Characteristics for a National System to Store, Retrieve, and Disseminate Water Data" as a report of the Federal Committee. The report also was endorsed by the Advisory Committee on Water Data for Public Use, and the USGS was urged to implement the system as soon as possible. The report was also distributed by the U.S. Committee as a contribution to the International Hydrological Decade. The

Federal Interagency Work Group on Designation of Standards for Water Data Acquisition completed the revision of their first draft and the report, "Recommended Standard Procedures for Water Data Acquisition," is undergoing review by the Federal Advisory Committee. The Committee also established an ad hoc work group to develop guidelines for future activities in the field of recommended procedures for water-data acquisition.

The Advisory Committee on Water Data for Public Use, at its seventh meeting, discussed the concept and the procedural aspects to the proposals for study of river quality, development of a program to assess the Nation's data on natural resources in relation to environmental problems, and the identification and completion of a water-use data base.

Water-data storage system

Data on daily discharge collected by the USGS and cooperating Federal and State agencies at regular streamflow stations for about 245,000 station-yr of record are stored on magnetic tape. This covers more than 70 percent of all the streamflow data collected under this program. The data are stored in discrete units of daily figures for water discharge from each gaging station for each year; thus, the data are compatible with a variety of statistical programs for analysis on the basis of calendar years, water years, climatic years, or any other desired period.

An automated system of storage and retrieval of surface-water quality data has been used since 1959. All data collected since then, plus selected long-term historical records, have been entered into the system, within which they are separated into five basic files as follows: (1) Chemical and physical analyses of surface water, (2) suspended sediment, (3) water temperature, (4) specific conductance, and (5) multi-item data collected by digital monitors.

The USGS has coded the data in machine format for about 40,000 ground-water wells and about 25,000 chemical analyses of water from these wells. The file, which uses the latitude-longitude system for locating wells, includes information relative to State, county, use of water, use of well, depth, drilling method, yield, water levels, physiographic data, and aquifer characteristics.

URBAN WATER PROGRAM

Progress continued during the year in hydrologic investigations in the urban environment; more than 320 projects of the Water Resources Division were either directly or indirectly related to urban water problems.

Development of hydrologic methods for use in urban water studies

The effort to develop a practical field method of measuring flow in storm sewers, under both open-channel and pipe flow conditions, continued. W. J. Schneider reported that two types of measuring devices, a modified venturi and a palmer-bowles flume, were tested and rated in the laboratory. The ratings appear to be satisfactory, and no scale factor was found. Preparations are now being made for field testing of the modified venturi device in a 30-in. and a 42-in. combined flood-sanitary sewer in San Francisco this year. Planning is also underway for installation of two additional flowmeters in the Philadelphia area during the coming year.

G. F. Smoot reported continued progress on the development of an automatic water-quality sampling system for use in the urban environment. A model was fabricated and is now being laboratory tested. Results so far indicate satisfactory performance. Planning is underway for installation and field testing of this system in connection with the installation of the flow-measuring devices in the Philadelphia area.

Studies of urban runoff and floods

Texas.—Urban runoff studies are continuing in Texas in cooperation with State and local agencies.

In the Dallas area, preliminary investigations by G. R. Dempster of average annual surface runoff from one rural and three adjacent urban basins showed that urban runoff is 1.4 to 1.8 times greater than rural runoff. The urban basins have impervious areas of 9 to 47 percent, with one basin fully developed. A parametric urban rainfall-surface runoff model, calibrated by using basins in the urban complex, makes it possible to extend flood-peak records in time by storm transposition (assuming present-day conditions). The extension encompasses precipitation records collected since 1913 and nine model parameters which relate soil moisture, evaporation, and infiltration variables to surface routing of precipitation excess.

Findings of model calibrations for seven gaged streams in the Dallas area, ranging in drainage area size from 4.75 to 66.4 sq mi and having impervious areas of zero to 47 percent, indicated reasonable stability and comparability of model parameters. Comparisons between synthetic- and observed-flood volumes and peaks showed an approximate average standard error of estimate of 30 percent based on 14 to 19 storms events per station recorded during the period 1962–70. The calibrations for the derived urban conditions and present model structure showed that runoff computed by the model occurs as soon as rainfall abstractions are satisfied and that synthetic peaks lead to observed peaks in time. Part of the differences between synthetic and observed times is attributed to the lack of constraints imposed upon the model. The amount of lead between the model and actual peak timing is grossly related to drainage-area size. Work is continuing on this modeling.

Basin models prepared by S. L. Johnson and D. M. Sayre to predict peak discharge from 28 urban basins in the Houston area were applied to long-term rainfall data to simulate annual peaks. T-year peaks were obtained by log-Pearson type III

analyses of the simulated peaks. Step-forward multiple regression was used to determine the relationship between the T-year events and basin characteristics. Those parameters determined to be useful in estimating T-year peaks were impervious area and channel rise or drainage area and percentage of impervious area. Standard error of estimate of the regression analysis ranged from ±25 percent of the 2-yr recurrence interval to ±37 percent of the 100-yr recurrence interval.

Missouri.—John Skelton reported that runoff volumes, flood peaks, and low flow were increased by urbanization in the St. Louis area. The amount of increase depends on the percentage of impervious area in a basin and the quantity of effluent entering the stream from sewage-treatment plants, septic tanks, industry, and storm sewers. Storm sewers, gutters, and manmade ditches greatly increase peaks over those from comparable rural areas during low-order floods but function less efficiently during greater floods, making the differences smaller. For instance, available data in the St. Louis area indicated that the 25-yr flood for a 60-percent urbanized basin is about 2.4 times greater than the 2-yr flood, whereas the same flood from a rural basin is about 3.4 times the 2-yr flood.

Virginia.—P. L. Soule reported that 11 maps and 59 separate sheets were prepared for Fairfax County, Va., showing the 100-yr flood limits, water surface contours, and flood profiles of selected recurrence interval floods. The 100-yr flood was delineated on standard 7½ minute quadrangle maps. To provide information for use in field determination of flood risk, the delineation covered approximately 180 linear mi of the approximate 250 linear mi of rivers and streams in the county where 100-yr flood plains average more than 400 ft in width and have drainage areas greater than 1 sq mi. Determination of the discharge of floods for given recurrence intervals was based on previous research of D. G. Anderson in his work in Fairfax County. The flood profiles were computed by standard backwater techniques based on channel and flood-plain data determined for the project.

New Jersey.—In a preliminary study of the potential usefulness of conventional methods for the evaluation of long-term hydrologic data for basins in various stages of urban development, S. J. Stankowski used overlapping 10-yr increments (1940–50, 1945–55, . . . , 1960–70) of annual-peak-discharge data to generate a series of 2-yr floods for each of four continuous-record gaging stations located in the same hydrologic area in New Jersey. The increment 1940–50 was used as a base period. No increase occurred in the magnitudes of the 2-yr floods for a rural station. For three urbanized stations, the magnitudes of the 2-yr floods increased progressively with time. The percentage increases in the 2-yr floods for the period 1960–70 from those of the base period ranged from 42 percent to 102 percent. This approach, along with the use of population density as an indirect indicator of past and present drainage-basin development conditions, is being used in an investigation of the effects of varying degrees of urban and suburban development on peak-streamflow characteristics in New Jersey.

California.—W. G. Hines and Joseph Goss reported that an intensive, urban-runoff, water-quality study for a residentially developed drainage basin in the Hayward, Calif., area is now underway. Streamflow is continuously measured, and water-quality sampling is conducted during most storm events. The program includes water-quality sampling for primary nutrients, oxygen-demanding substances, heavy metals, pesticides, coliform bacteria, greases and oils, major ions, and field measurements, such as pH and alkalinity. The program is designed to determine the magnitude and variability in constituent concentrations during individual and seasonally progressive runoff events. Concentrations of many of the constituents, such as primary nutrients, oxygen-demanding substances, and coliform bacteria, are similar to those reported in previous studies. Results of heavy-metal and pesticide analyses indicate significant concentrations in both storm-water runoff and associated sediments. These results are unique in that very little documentary evidence of the magnitude of heavy-metal and pesticide concentrations in urban storm-water runoff is available from previous studies. Within the heavy-metals group, concentrations of lead have been the most significant, ranging from 11 μg/l in a low-flow sample to 680 μg/l in a sample of early season runoff. Pesticide concentrations in bottom sediment for DDT, dieldrin, and chlordane were 37, 46, and 187 μg/kg, respectively, of dry solids for a sample taken during the prestorm season. These insecticides have been detected in much lower concentrations during runoff sampling (water samples); however, several of the chlorinated-hydrocarbon herbicides, such as 2,4-D, have been detected in concentrations as much as 6.4 μg/l in water samples.

Urban water-resources studies

Massachusetts.—S. J. Pollock reported that an investigation of ground-water contamination associated with highway-deicing chemicals and monitoring of selected wells continued in 1971 in Massachusetts. Increases in the concentration of chloride at eight monitoring sites during 1971 ranged from 25 to 100 mg/l. The highest concentration of chloride measured in 1971 was 380 mg/l. The increases reflect the continued general increase in the use of sodium chloride and calcium chloride for highway deicing. In Auburn and Weston, municipal wells were shut down when the concentrations of chloride exceeded 500 and 300 mg/l respectively. The chloride concentration of water from a well 1,100 ft from a covered salt-storage pile at Reading increased to 200 mg/l from 160 mg/l in 1967 when the cover was installed. In Burlington, where salting of local streets was banned in 1970, the concentration of chloride in the town's main well field dropped from a range of 100 to 270 mg/l to a range of 100 to 180 mg/l.

An interesting ground-water subregimen has been recognized by J. E. Cotton and D. F. Delaney as part of their study of ground-water levels in Boston, Mass. In some areas of Boston's

Back Bay the water table becomes perched during dewatering for construction of substructures. Water is perched in sandy fill by relatively impermeable silt or mud deposits overlying temporarily dewatered sand and gravel. Where the silt and mud deposits are thin or absent, the water table is simply lowered by dewatering and does not become perched. Dewatering during construction within Back Bay produces short-term changes in water levels which return to prepumping water-table condition when dewatering ends. Relative stability of the water table is essential in land-fill areas of central Boston because structural damage to older buildings commonly results from rapid deterioration of old wooden foundation pilings if the soil about pilings becomes unsaturated.

Minnesota.—R. F. Norvitch, T. G. Ross, and Alex Brietkrietz reported that a transitory cone of depression, brought about by increased summertime ground-water withdrawals, occurs annually in the Minneapolis–St. Paul metropolitan area, Minnesota. Mass water-level measurements made in about 180 wells in the Prairie du Chien–Jordan aquifer in late December 1970 and late August 1971 provided data for the determination of the dimensions of this transitory cone. The cone encompasses an area of about 770 sq mi, has an average head change of 8 ft, and a volume of about 1.2 cu mi. The summertime pumping rate in the Prairie du Chien–Jordan aquifer was computed to be 246 mgd for 120 days which exceeds the base daily pumping rate of 111 mgd by 135 mgd. The cone of depression resulting from pumping at the base daily rate encompasses an area of about 740 sq mi, had an average head change of 23 ft during the period 1885–1970, and has a volume of 3.2 cu mi. The overall cone of depression during the summer encompasses an area of about 770 sq mi, has a head change of 31 ft, and has a volume of 4.4 cu mi (short-term unit yield, 10,300 gpd per sq mi per ft of decline).

Kansas.—H. G. O'Connor (Kansas Geol. Survey) compiled information that is presented as a series of maps that show flood-prone areas, natural drainage basins, soil classification, depth to bedrock, location of mineral resources including construction materials such as limestone and sand and gravel, and the yields that can be expected from water wells in Johnson County, Kans. Because it is a part of the Kansas City metropolitan area, Johnson County is faced with the problems of a rapid urbanization.

New York.—Suffolk County has experienced rapid growths of population and industry. Drainage from cesspools and leachates from fertilizers have led to increasing contamination of the county's ground water—currently the sole source of water supply. The contamination, chiefly nitrate and synthetic-detergent constituents, has occurred mainly in the upper glacial aquifer in the western half of the county. Water-management officials are faced with problems of providing increasing water supplies, protection of the supply system, disposal of wastes, and maintenance of local environment and ecology. About 300 shallow observation wells are to serve as regular sampling points for a program of monitoring water levels and chemical quality in the upper glacial aquifer.

Alaska.—In Alaska several studies are related to the growing urban water problems. According to W. W. Barnwell, the cooperative geohydrologic study of the Greater Anchorage Area Borough continued in 1971. Ground water in the Anchorage lowlands may yield between 20 and 40 mgd. An average of approximately 11 mgd was pumped during 1969. Maximum yield will depend upon the success of future artificial recharge. Projections of area water demand and availability indicate the necessity for the development of supplementary water sources by 1976 at the earliest and 1986 at the latest. A storage dam could be built on Ship Creek or Eagle River.

Increased emphasis during the year was placed on environmental hydrologic problems related to land-use planning and development. The following projects were initiated: R. S. George began an analysis of the effects of wetland drainage on water levels of lakes in the Anchorage lowlands. L. L. Dearborn undertook a study of water availability and pollution susceptibility in the rapidly developing residential "Hillside" area located 8 miles southeast of Anchorage. Chester Zenone began a report summarizing water availability in the Eagle River–Birchwood area, 15 mi north of Anchorage. Studies of analog modeling and artificial recharge status were continued by J. B. Weeks and W. W. Barnwell. Water-spreading experiments on a site of half an acre near Ship Creek indicated an infiltration rate of 16 gpd per ft. Additional artificial-recharge studies are planned for Ship Creek and for other sites on the North and South Forks of Campbell Creek.

Because of intensive urban renewal and scarcity of suitable construction sites, there is a shift of population and business away from Juneau to the Mendenhall Valley, about 10 mi to the north. The new sewer system for the valley (scheduled to begin operation in 1972) and a proposed central water system will alter distribution of the area's water resources. Also of concern are changes caused by landfill, stream channeling, and waste disposal. J. A. McConaghy and W. N. Bowman are continuing a study of water management and of the effects of urbanization in the area. Results of the cooperative water resources program between the USGS and the city and borough of Juneau are being incorporated into the regional plan to control development of the area.

According to G. S. Anderson and S. H. Jones, ground-water and lake levels in the developing Kenai area are generally recovering from the drought conditions of 1968 and 1969. However, water levels in a few lakes near the major ground-water pumpage center declined during 1971, and the study is being continued to determine the relationship between declining ground-water and lake levels. Studies to date indicate that the artesian aquifer is being recharged by leakage through the confining beds.

Florida.—J. E. Hull reported that peak pumpage by the city of Miami reached 203 mgd during April 1971. He also reported that in 1971 the salt front moved inland southward from the Miami Canal to Canal 111. The most threatening advance occurred near the Miami Springs–Hialeah well fields and the

Homestead Air Force Base well field. From an analysis of samples of bottom sediments in the Miami Canal, F. W. Meyer and J. E. Hull computed the permeability of the material as about 0.3 m per day. During 1971, the maximum head loss across the bottom sediments was about 2 m near the center of well-field pumpage.

C. B. Sherwood, H. J. McCoy, and C. F. Galliher reported that mushrooming population in Broward County, Fla., is causing problems of contamination by effluent wastes and sea-water intrusion along with rapidly increasing water demands. The chief threat to water resources is the disposal of treated-sewage effluent into the network of controlled canals which cut into the highly permeable shallow aquifer. During dry periods the aquifer is replenished chiefly by infiltration from the canal system. Present and future water needs may be met if strict water-management practices are followed to reduce losses of fresh water to the sea, to minimize contamination, and to locate major new well fields inland from the coast. The current implementation of a regional concept for county-wide water and sewage facilities will aid in meeting these needs.

H. J. McCoy and C. B. Sherwood reported that the completion of a feeder canal from Middle River Canal through the large (40 mgd) Prospect well field in Fort Lauderdale, Fla., contributed significant recharge to the well field during the record dry period of January–June 1971. Improvements in the connection between the Middle River Canal and the inland water-conservation areas of the regional water-management system will more than double the recharge potential of the Middle River Canal to the well field. This recharge will become increasingly important as the well field is expanded to supply central Broward County with over 100 mgd of treated ground water.

Chemical analyses of water from test wells near the 60-ft supply well of Hollywood, Fla., showed that better quality water could be obtained from depths below 100 ft, according to H. W. Bearden. The results of test drilling in the area of the proposed well-field expansion in the southwest part of the city indicated that permeable limestone and shell at depths of 134 to 159 ft would be excellent for development of supply wells. During the dry season, the chloride content of Hollywood Canal is more than 10,000 mg/l. Control of salt water in the canal would require both a salinity barrier and a source of fresh-water replenishment.

Erosion and sediment

T. H. Yorke reported on the continuing study of hydrology and sedimentation in the headwaters of Rock Creek and Anacostia River basins near Washington, D.C. Water discharge and suspended-sediment concentration have been monitored at nine sites since 1966 for the purpose of evaluating the changes in the water regimen as a result of urbanization and the effectiveness of sediment-control techniques used in urban construction. A significant increase in storm runoff and suspended sediment has been observed in the urbanizing basins. The mean concentration of suspended sediment transported by storm runoff has ranged from 700 mg/l in an undeveloped basin to 10,000 mg/l in a basin with active construction.

Hydrologic effects of waste disposal

Florida.—J. J. Schneider and H. G. Rodis reported that in Palm Beach County, Fla., water samples from 14 observation wells of various depths and an inventory of private wells of various depths indicate contamination of the shallow aquifer under and in the area surrounding the disposal site, with contaminants moving out in all directions. No total or fecal coliforms were found in any of the three observation wells located at the southeast corner of the disposal site. Bacteria were found in one shallow observation well one-fourth of a mile southeast of the site. No bacteria were found in deeper wells at the same location.

D. H. Boggess reported that water samples obtained from shallow observation wells in a landfill operation near Fort Meyers, Fla., show contamination of the water-table aquifer in the vicinity of the landfill operated by the city. In one well, the iron and calcium contents were nearly doubled; the magnesium, organic nitrogen, and dissolved solids were nearly tripled; the chloride and sodium contents were six to seven times greater; and the sulfate and ammonia concentrations were eight to 10 times greater than for a comparable control well.

In a study of the effects of spray application of sewage effluent, R. N. Cherry reported that batteries of wells have been installed at the spray irrigation site and adjacent area in Pinellas County, Fla. Wells in each battery range in depth from 2 to 50 ft. The surficial sand at the site is about 15 ft thick and is underlain by a clay layer which is also about 15 ft thick. Samples of the soil material have been collected and are being analyzed for permeability, particle-size distribution, ion-exchange capacity, and percentage of base saturation. In addition, background information is being obtained on the quality of water in the surficial sand. Among the constituents being determined are concentrations of selected trace metals, nutrients, and coliform bacteria.

New Jersey.—E. G. Miller found that effluents discharged by nine sewage treatment plants in the Cooper River basin upstream from Haddonfield, N.J., on June 11, 1971, totaled 6.8 cfs at a time when the total streamflow at the gaging station at Haddonfield was only 17.9 cfs. Thus, as much as 38 percent of the flow on that day could be attributed to sewage flow. As records of the sewage-treatment plants show that the daily average quantity of effluent is relatively constant and the total streamflow of Cooper River at Haddonfield sometimes is 12 cfs or less, there are probably times when more than half the flow at Haddonfield originates as effluent from sewage-treatment plants.

New York.—A. D. Randall and D. A. Rickert reported on their continuing study of the new landfill site at Catskill, N.Y. Water-quality parameters have been selected to determine the frontal movement of rapidly migrating leachate material and the concentrations of toxic trace metals and nutrients. Initial data on ground and stream water indicate that leachate contamination so far has been contained in the unsaturated zone. Suction lysimeters have been installed to determine the movement and quality of soil water.

Oregon.—D. A. Rickert reported that a new landfill site is being studied in Portland, Ore. A landfill was operated there for 12 yr but was closed. The site under study is situated on basalt, a condition highly conducive to the pollution of ground- and surface-water resources. Stream, well, and spring waters are being analyzed for pesticides, nutrients, toxic trace metals, and bacterial contamination.

Real-estate lakes

D. A. Rickert reported on the continued impact of urbanization on Lake Anne, an 8-yr-old real-estate lake in Reston, Va. The lake is highly eutrophic and during summer is sharply stratified with a zero DO condition from 12 ft down to the maximum depth of 30 ft. The lake surface has yet to exhibit algal blooms, and tests are being conducted to determine whether the cause is a lack of minor nutrients, a lack of sufficient light penetration, or toxicity. Major nutrient contents continued to be high, the only possible unnatural sources being direct runoff from fertilized lawns and gardens and storm-water runoff from streets and parking lots. Sediment accumulation is continual, but the rate is suprisingly low considering the large amount of building and road construction. Bacterial contamination is low or nonexistent. However, the concentrations of certain insecticides and PCB is alarmingly high in the bottom sediments and also in several analyzed fish. The only possible insecticide source is lawn runoff. The source of PCB is unknown but under investigation.

WATER USE

Water use in the United States

C. R. Murray and E. B. Reeves (1972) estimated that off-channel water use in the United States increased 19 percent in the 5-yr period, 1965–70. In 1970 an average of 370 bgd—a per capita use of 1,800 gpd—was withdrawn for public supply, rural (domestic and livestock), irrigation, and self-supplied industrial uses. In 1970 about 78 percent of the 214 bgd of self-supplied industrial water was used for cooling purposes in thermoelectric powerplants. Since 1965, the quantity of fresh water withdrawn by thermoelectric powerplants increased about 34 percent, and the quantity of saline water withdrawn increased about 30 percent. Hydroelectric powerplant withdrawals—a within-channel, nonconsumptive use—increased 22 percent to 2,800 bgd in 1970. Fresh water consumed by all off-channel uses averaged 87 bgd, and saline water averaged 1.4 bgd; together these represent a 13 percent increase in 5 yr for total water consumption. Ground water supplied 69 bgd (of which 1 bgd was saline) and surface water supplied 300 bgd (of which 54 bgd was saline) for off-channel use. Reclaimed sewage supplied 0.5 bgd for irrigation and industrial uses.

The average annual streamflow is about 1,200 bgd, that is, 3.2 times the average national off-channel withdrawal use and 13.8 times the average national consumption. However, supply-demand relationships are complex, and only a part of the total runoff can be retrieved for use. The available supply varies widely in time and place; the demand in each of the WRC (Water Resources Council) regions was compared to estimated supply and to another index of constancy of supply (the annual flow exceeded in 90 percent of years) in the WRC regions. The eastern regions and the Columbia–North Pacific region, in general, show abundant and dependable supplies, but in most of the western regions, demand is greater than the flows exceeded in 90 percent of the years. Water-management methods consisting of mining of ground water, repeated withdrawals of the same surface water, and importation of surface water have augmented the natural surface-water supplies of many of the western regions and have made it possible for them to withdraw quantities greater than the local surface-water supply.

Water use in Arkansas in 1970

H. N. Halberg reported that water use for off-channel purposes in Arkansas in 1970 was 3,061 mgd, 28 percent more than in 1965. Forty percent of the water withdrawn for use was consumed. Irrigation utilized 1,293 mgd of which 82 percent was ground water. The largest increases in use were by self-supplied industry (from 130 to 209 mgd), for fish farming (from 209 to 314 mgd), and for thermoelectric-power production (from 423 to 956 mgd). Water withdrawn for hydroelectric-power production, an in-channel use, was 24,700 mgd, an increase of 13,700 mgd in 5 yr.

Deposits of Quaternary age provided most of the water used for irrigation and fish farming; the Sparta Sand, of Eocene age, provided much of the water used for industry and public supply.

Ground-water withdrawals in middle Peace and upper Alafia River basins, Florida

Ground-water withdrawals from the Floridan aquifer in the middle Peace and upper Alafia River basins were about 128 billion gal in 1970 as compared with 50 billion gal in 1950. Industrial water use, principally for phosphate mining and processing, accounted for 66 percent of the total withdrawals in 1970. Of the remainder, citrus-irrigation needs accounted for about 26 percent and municipal supplies accounted for 8 percent.

Water use in Georgia in 1970

A. M. F. Johnson reported that water withdrawals in Georgia for off-channel and hydroelectric-power uses increased about 15 percent from 1960 to 1970; during the same 10-yr period, the population increased 16 percent. From 1965 to 1970, however, the average annual increase in water use was 2.4 percent. The withdrawal of water for generating hydroelectric power, the major water use in the State, increased at an average rate of about 1 percent per yr from 1965 to 1970. During the same period, municipal use increased 8 percent annually and industrial use increased 14 percent annually.

Utilization of water resources in Gray County, Kansas

A water-resource study of Gray County by H. E. McGovern and W. A. Long indicated that large quantities of ground water chemically suitable for irrigation are contained in alluvium of Pliocene and Pleistocene age. An estimated 15 million acre-ft of recoverable ground water is in storage. Wells in the alluvium yield from 500 gpm to more than 2,000 gpm, depending on the local lithology and saturated thickness of the deposits. Long-term water-level declines are less than 10 ft in most of the county. In 1970, about 200,000 acre-ft of ground water was withdrawn from 610 irrigation wells. The Arkansas River, which is the natural drain of the ground-water reservoir in Gray County, gains an average of 11,000 acre-ft of streamflow per yr.

Large withdrawals of ground water affect the water table in Chase County, Nebraska

C. F. Keech reported that the water table in west-central Chase County, Nebr., is lowering as much as 2 ft per year owing to the large increase in pumpage for irrigation since 1967. Prior to 1967, ground-water development was small enough that recharge of the ground-water reservoir by precipitation nearly balanced the withdrawals. In recent years, installation of high-capacity wells equipped with large automatic pivot-sprinkler systems has greatly increased the rate of withdrawal. More than 300 high-capacity irrigation wells were installed during the 5-yr period 1967–72. Continuation of such a rate of expansion will cause serious depletion of the ground-water supply in a few years.

The water-yielding sediments consist principally of Pliocene continental deposits (Ogallala Formation) that are silt, silty sand, sand, gravel, and poorly consolidated sandstone. The thickness of the deposits ranges from about 50 to more than 300 ft.

Net loss in ground-water storage in irrigated areas in Clay, Hamilton, and York Counties, Nebraska

Ground-water withdrawals during 1971 in the upper Big Blue River basin in Clay, Hamilton, and York Counties, Nebr., caused an average water-level decline of a little more than 3 ft. To what extent water levels will have recovered before the 1972 irrigation season begins is not known, but indications are that the depletion of ground-water storage in 1971 was greater than in any previous year. In 1970, the net loss from storage in the three counties was 325,000 acre-ft. About 75 new irrigation wells are drilled in the area each year, thus increasing the demand on the stored supply. Even though propitious precipitation reduces the need for irrigation pumpage in some years, the long-term water-level trend is downward.

INTERNATIONAL HYDROLOGICAL DECADE, 1965–74

The USGS continued its participation in the 10-yr program of cooperative international studies in scientific hydrology known as the International Hydrological Decade (IHD). The network of 82 river stations for observing and recording streamflow, chemical quality, and suspended-sediment load was maintained. This network provides a general index of the discharge of surface water and of dissolved and suspended material from the continent to the oceans. Observations were continued at 23 lake and reservoir stations and at selected wells; these stations furnished data on the chemical quality of lake and reservoir waters and ground water and on water levels.

Hydrologic bench marks, established at 46 localities, provide information on natural hydrologic conditions largely removed from the effects of man's activities. Measurements of the tritium content of water in the 20 principal rivers in the United States, and of precipitation at 16 localities, are being used to evaluate the effect of precipitation on the chemical character of inland waters.

Hydrologists of the USGS participated in international symposia, seminars, meetings of working groups, intercountry exchange of experts, discussions of selected activities chosen for particular years, and hydrologic research at selected areas in the United States, where the results are expected to have international application. A discussion of some of the activities follows.

E. L. Hendricks, chief of the United States delegation, participated in the seventh session of the Coordinating Council for the IHD in Paris in November 1971.

R. L. Nace continued his activities for the IHD as a member of the Working Group on Water Balances. He also participated in the official opening ceremonies of the International Field Year for the Great Lakes (IFYGL), which were held on March 30, 1972, at the Canada Centre for Inland Waters at Burlington, Ontario.

R. L. Cory continued water-quality monitoring and studies of the epifauna in three small estuarine tributaries (South River, Rhode River, and West River) on the west side of Chesapeake Bay, in Anne Arundel County, Md.

M. F. Meier participated in meetings of the International Commission on Snow and Ice at the General Assembly of the International Union of Geodesy and Geophysics in Moscow in

August 1971. Selected glaciers in Alaska and the Western States were monitored by Meier, L. R. Mayo, and W. V. Tangborn.

E. C. Rhodehamel, G. K. Schultz, and W. N. Embree continued hydrologic observations in the portion of Lake Ontario basin within the United States as part of the IFYGL program.

Allen Sinnott and R. L. Nace continued bathymetry studies in the Rhode River estuary and collected additional samples of bottom sediments.

G. F. Smoot, assisted by Brazilian engineers, measured the discharge of the Amazon River at Óbidos, Brazil, on June 5, 1972; the rate was determined to be 255,000 m^3 per sec (about 9,000,000 cfs—the highest flow ever measured).

MARINE GEOLOGY AND HYDROLOGY

MARINE AND COASTAL GEOLOGY

The continental margins are an important potential source of the fuel and raw mineral resources required by our growing and increasingly urbanized population. Knowledge of the geology, the mineral resources, geologic processes, and the environmental relationships of the coastal zones, the adjacent shelves, and the deep ocean is urgently needed to solve the problems generated by increased and often competitive demands on the resources of these regions.

The USGS is continuing diversified geologic investigations in the Nation's surrounding marine environment. Studies are being conducted in the Atlantic, Gulf of Mexico, Pacific, and Alaskan continental margins and in the Caribbean Sea. Participation in the IDOE and the DSDP has extended these studies to the deep ocean as well. Many of the investigations involve cooperative arrangements with other Federal agencies, with State governmental agencies, universities, oceanographic institutions, and international organizations. Results of the past year's research programs in marine and coastal geology are summarized below.

ATLANTIC CONTINENTAL MARGIN

Offshore resources of the northeast United States.—F. T. Manheim (1972) has compiled data on offshore mineral resources, exclusive of oil and gas, adjacent to the northeastern United States. The chief resources are sand and gravel which are present in enormous quantities and may come into utilization for coastal communities once appropriate investigatory and regulatory guidelines are worked out. At the present, there is a virtually complete moratorium on leasing or exploitative activities both on State and Federal levels. In addition to the sand and gravel deposits studied by J. S. Schlee, certain types of muds, including polluted muds in estuaries, have been shown to form an excellent raw material for building ceramics. Further, the new processes can potentially utilize dredgings from navigable channels; disposal of such materials otherwise poses a serious problem for the near future. In contrast to the above, metal or placer deposits are not promising or remain to be explored in subsurficial deposits.

Seismic studies in the western Gulf of Maine.—Seismic studies by R. N. Oldale (USGS) and Elazer Uchupi and K. E. Prada of the WHOI have revealed additional information on the sedimentary framework of the western Gulf of Maine. (See Oldale and others, 1972.) Basement is mostly crystalline rock of Paleozoic age. Stratified rock within the basement is inferred to be of Triassic age and similar to that in the Bay of Fundy. Coastal Plain and older glacial drift occur beneath Cape Cod Bay and the major bathymetric highs. These older rocks are separated from the drift of the last ice by a major unconformity. Glacial moraines similar to those of Long Island and Martha's Vineyard form the upper part of Stellwagen Bank and Jeffreys Ledge. The youngest glacial sediments include glaciolacustrine deposits in Cape Cod Bay and glaciomarine deposits in Stellwagen, Scantum, and Porpoise Basins. These deposits are capped by silt and clay winnowed from the highs and deposited in the basins during the late Pleistocene-Holocene rise in sea level.

A drainage system, little modified by the last glaciation, is defined by the sediment distribution. The valleys are offshore extensions of onland rivers which eroded the Gulf of Maine during late Tertiary or early Pleistocene time.

Currents and sediment distribution off Massachusetts.—J. S. Schlee, C. J. O'Hara, D. W. Folger and J. M. Robb report that the distribution of sediment on the sea floor between Cape Ann and Cape Cod is related to bathymetry, currents, and source areas. Nearshore and on banks where current flow is greatest, gravel and sand predominate. Much fine detritus apparently is swept from shallow areas into the basins where current flow is weaker. There silt and clay are abundant although sand is common near elevated features. These recent sediments appear to be burying the lag deposits that are relict from the last glaciation.

Bottom currents are mainly tidal and flow over banks at maximum velocities capable of transporting coarse sand (45 cm/sec). Residual bottom current flow is generally southward except nearshore where shoreward motion predominates. The basins are typified by relatively sluggish bottom-water velocities of only a few centimeters per second.

Colloidal phenomena in an estuarine environment.—I. A. Breger (1970), Peter Zubovic, and J. C. Chandler report that colloidal substances isolated from waters of the Chesapeake Bay have a high content of magnesium. Colloidal substances isolated from the sediments, on the other hand, have a high content of manganese with lesser contents of magnesium, calcium, aluminum, phosphorus and other elements. Organic

colloids may indeed play an important role in the formation of manganese nodules.

GULF OF MEXICO AND CARIBBEAN SEA

Crust and mantle studies.—In fitting continental masses into some protocontinent, it has become standard practice to outline pieces of the jigsaw puzzle by extending the assumed continental segment out to some arbitrary water depth—the 500-fathom line, for example. H. L. Krivoy reports that, in the West Florida Shelf and in many other maritime areas for which gravity data are available, there are alternatives based on 0- or +10-milligal isogal contours. These data predict that transition from continental geometry is not always clearly associated with continental shelf, scarp, or deep ocean; at such places as Brownsville, Tex., New Orleans, La., or the Yucatan Peninsula, this transition lies beneath the modern land area. There are other places where Bouguer fields, which indicate continental geometry, coincide with modern shelves such as those beneath the present shelves off Texas and Florida.

All data gathered so far indicate that these models have universal applicability; some anomalies are explainable in terms of deltaic growth, others in terms of reef progradation, and others as accretionary remnants. It seems desirable that areas being used for global continental reconstruction should first be trimmed to their original dimensions as suggested by Bouguer field values. It is also desirable that investigators should extend gravity coverage along the shores of modern seas, both offshore and onshore.

Seismic reflection profiling in western Gulf of Mexico.—A reconnaissance investigation by L. E. Garrison, Erk Reimnitz and R. G. Martin, Jr., (1972) using seismic reflection techniques aboard the Mexican Navy RV *Cadete Virgilio Uribe* in the western Gulf of Mexico has revealed a general correspondence between geologic provinces in the coastal plain of southern Texas and eastern Mexico and the physiography and structure of the adjacent continental shelf and upper slope. Preliminary examination of the acoustical profiles confirms a threefold division of the western gulf margin into distinctive subsea provinces and details the nature and location of their boundaries.

Off southern Texas and northern Mexico, the margin is essentially a continuation of the salt dome province of the northwestern gulf. Its seaward boundary is the Rio Grande salt front which strikes southwesterly from Texas toward Tampico, Mexico. The central part of the margin is characterized by ridges of folded sediment spaced 10 to 12 km apart with relief as great as 500 m. Ridgetops, which are correlatable from profile to profile, confirm their continuity over great distances. Toward the upper slope and shelf the folds have been buried by outward-building sediments. The folds apparently terminate near Veracruz, perhaps in relation to possible seaward extensions of the trans-Mexico Cenozoic volcanic belt and a belt of volcanic rocks that extends discontinuously into Guatemala from the Bay of Campeche.

The third province extends northward from the Tabasco-Campeche (saline) basin where numerous salt and anhydrite anticlines are present near the coast. Here, the thick blanket of shelf and slope sediments have been intruded by large diapiric masses to produce a province closely related, both physiographically and structurally, to the northwestern gulf off Texas and Louisiana. Seismic profiles show that the diapirism on the shelf and upper slope is confined to a zone of about 150 km in width and extends to the Sigsbee Knolls in the central gulf.

The seismic reflection profiles from this investigation disclose a vast number of structural features in the continental shelf and upper slope of the western gulf that have a high potential for oil and gas entrapment.

Interstitial salts in sediments of the Gulf of Mexico.—Studies by F. T. Manheim (USGS) and F. L. Sayles and L. S. Waterman (WHOI) on DSDP cores have obtained new insights into the substructure of the Gulf of Mexico. Previous work on interstitial waters in sediments of the Gulf of Mexico have shown that salt deposits at depth reveal themselves by anomalous increases in interstitial salts as much as several kilometers higher in the sedimentary section. The new data show that holes in the Sigsbee Knolls trend confirm presence of salt at depth, but elsewhere in the Gulf of Mexico there appear to be no evaporites at depth. This finding sheds doubt on the concept that the entire Gulf of Mexico was once floored by rock salt of the Louann Salt sequence.

Movement and deformation of turbid-water plumes.—Studies by R. E. Hunter and G. W. Hill of aerial photographs suggest that most of the suspended particulate matter along the south Texas coast in December 1968 entered the Gulf of Mexico through Aransas Pass. Turbid-water plumes apparently developed during each tidal outflow and were subsequently carried southward by currents paralleling the shore. The plumes were quickly deformed by current shear and were gradually disrupted by helical (Langmuir) circulation. Evidence from the photographs suggests that the suspended matter, originally concentrated in plumes at the sea surface, had become concentrated in a bottom layer by the time it had drifted 80 km south.

Turbid water carried into the nearshore bar-and-trough system was discharged seaward by rip currents. By comparing two sets of aerial photographs taken a short time apart, the rip current plumes were found to drift along shore and to be deformed by current shear. The drift velocity parallel to shore was found to range from 0.60 km/hr at 1,160 m offshore to 1.06 km/hr at 365 m offshore.

Processes influencing nearshore bar stability.—Studies by R. E. Hunter of nearshore bar-and-trough systems along the Texas coast have led to the discovery of several processes that may be instrumental in maintaining long, straight, shore-parallel bars and troughs in equilibrium with the hydrodynamic regime. These processes seem capable of carrying sand seaward across the landward side of a bar and over its crest in amounts large enough to balance the amount transported

landward by asymmetric wave surge.

The process is probably most responsible for sweeping sand up the landward side of a bar in a helical circulation cell similar to those found leeward of oblique current ripples or megaripples in rivers. Observations of slightly buoyant drifters by divers using SCUBA revealed a pattern of near-bottom residual currents consistent with the existence of a helical vortex centered over the trough axis.

Rip currents that move with the longshore current are probably most responsible for carrying sand seaward over the bar crest. The fact that the rip currents do not remain spatially fixed evidently accounts for the absence of channels cutting through the bars. The existence of moving rip current plumes was shown by aerial photographs taken at short time intervals along a section of coast.

Isotopic dilution model predicts uranium concentration.—By alpha-spectroscopy, C. W. Holmes determined the uranium concentration and isotopic composition of water and suspended sediment in the Nueces River, Nueces Bay, and Corpus Christi Bay. The average dissolved uranium concentration and radioactivity ratio (U^{234}/U^{238}) of the river water was determined to be 2.44 μg/l and 1.15 respectively. The water of a tributary of the main river was found to contain an average dissolved concentration of 42.8 μg/l and isotopic radioactive (U^{234}/U^{238}) ratio of 1.59. Close inspection of the lateral distribution and isotopic composition of the river showed that there was a marked increase in both parameters below the confluence of the tributary and the main stream. A model, based on equations used in isotopic dilution analysis, was derived which predicts these increases within analytical error. This model may be useful in subsequent studies to aid in the location of uranium deposits.

Caribbean margin of the Yucatan Peninsula.—J. G. Vedder and W. P. Dillon (Vedder and others, 1971) report that the continental slope east of the Yucatan Peninsula is characterized by a steep gradient from near the shoreline to a depth of about 1,000 m. Seaward from the narrow shelf several elongate reefs, banks, and islands interrupt the slope and lie parallel to the coast. Farther basinward the sea floor slopes gradually to depths of about 1,200 to 1,800 m where another set of ridges, not evident on existing charts, projects above the regional gradient and also lies parallel to the coast. A relatively sharp declivity on the east side of this ridge system drops to the floor of the Yucatan Basin at a depth of about 4,000 m. Dredge hauls from near the base of the slope in the Yucatan Channel and off Isla de Cozumel contained pre-Cretaceous(?) muscovite schist and marble and suggest that the two subparallel sets of ridges are formed by a broad belt of relatively resistant, metamorphosed sedimentary rock that extends northeast from the Maya Mountains of British Honduras into Isla de Pinos, Cuba. Elongate basins partially filled with Upper(?) Cretaceous and younger sediments separate the main ridges. The fill may be as thick as 2,000 m in the borderland basin east of Isla de Cozumel where the sedimentary rocks and overlying unconsolidated deposits also are broadly folded and locally faulted. The outer ridges serve as depositional barriers to sedimentation in smaller troughs developed along the east edge of the ridge-basin system. Presumably the relatively high standing basement structures represent rotational fault blocks formed during the large scale rifting that initiated continental margin development in post-late Paleozoic to pre-late Mesozoic time. Some recent activity, however, also is indicated by extensional faults in the nearshore basin sediments. This late movement of the blocks may have accompanied seismic events along the nearby boundary of the North American and Caribbean lithospheric plates.

Evidence of late Cenozoic volcanism, Gulf of Mexico.—Gravity, magnetic, and acoustic-reflection profiles recorded in the southern Gulf of Mexico as part of the IDOE reveal sea-floor volcanoes along a line connecting the Trans-Mexico and Guatemala (Tuxtlas) onshore volcanic belts. G. W. Moore reports that the most prominent offshore volcano is 45 km directly east of Veracruz, Mexico, at a depth of about 900 m. It appears near the base of the continental slope as an area of ragged topography and, in common with nearby onshore volcanic areas, is characterized by a high gravity anomaly (free air, 85 mgal; bouguer, 115 mgal).

Although nearby onshore eruptions have occurred during historic time, some antiquity is indicated by a negative magnetic anomaly at this submarine volcanic center since the present (Brunhes) positive magnetic field of the earth has existed for about 700,000 yr. Other centers along the submarine volcanic line, however, are characterized by positive magnetic anomalies.

The Trans-Mexico volcanic belt has been inferred in some tectonic models to extend as a fracture zone far out into the Gulf of Mexico or even beyond, but evidence from this study indicates that the submarine volcanism is essentially restricted to the southwestern continental margin of the gulf. The Trans-Mexico and Guatemala volcanic belts are interpreted to represent a cuspate pair of volcanic arcs related to the Middle America Trench which lies on the Pacific side of Mexico. Such an interpretation is supported by the fact that the cuspate line of volcanoes on land and under the Gulf of Mexico is followed by a matching band of intermediate-focus earthquakes subparallel with the trench.

Detailed study of a shelf area off Puerto Rico.—Studies by L. E. Garrison and C. W. Holmes of surface sediments in the offshore part of the Santa Isabel quadrangle were augmented by high-resolution seismic profiling and provided new data for the interpretation of depositional processes on the Puerto Rico shelf. A local northeast-southwest structural grain is controlled by the scarp of the Muertos normal fault in the north and a buried wave-cut terrace in the southern part of the quadrangle. Both features have been partially buried by Holocene deposition. The fault is down to the north with about 40 m displacement near the surface. It has been buried, however, by principally sand-size, biogenic sediment swept off the shallower platform adjoining it on the southeast. Finer material

removed in the winnowing process is deposited in a structural basin northwest of the fault.

Approximately 4 km to the southeast, the fault scarp is paralleled by another buried scarp formed by wave erosion during lower sea level. The scarp is capped by reef material giving it a present relief of less than 10 m, although its buried relief is nearly 30 m, so that the floor of the excavated terrace lies 40 to 45 m below present sea level. The coarse material covering this terrace is largely biogenic on the surface, but its worn and iron-stained appearance suggests that deposition ceased when the strand line moved shoreward.

Significant resources of sand and gravel may be associated with similar structural and erosional features elsewhere on the insular shelf.

Structure of Curaçao Ridge on the Venezuelan continental borderland.—Interpretation of reflection profiles reveals intense deformation of sedimentary rocks under the east-trending Curaçao Ridge, a 300-km-long feature that forms the northernmost structural high of the Venezuelan continental borderland. Horizontally layered strata in the Venezuelan Basin north of Curaçao Ridge are deformed along the north flank of the ridge. Layer B, known to be basaltic by the results of five DSDP holes, passes beneath part of the deformed strata on the north flank of the ridge. Oblique subduction of Caribbean oceanic crust beneath the continental margin can explain the observed structure. The deformation of the ridge may play an important role in the strain pattern between the Caribbean and South American plates. The research is part of a joint study of the Venezuelan borderland by USGS, Venezuelan, and Dutch scientists. Geologists participating in the study are: E. A. Silver, principal investigator, J. C. Case, J. P. Lockwood, H. G. Greene, P. R. Carlson, K. G. Blom, A. R. Tagg, H. L. Krivoy (USGS), H. G. MacGillavry (Univ. of Amsterdam), Rinus Wortel (Univ. of Utrecht), Jorge Navarro, Xavier Picard, J. A. Jimenez, Nelson Aboud (Venezuelan Ministry of Mines and Hydrocarbons), Alvaro Acosta and Enrique Vasquez (Venezuelan Petroleum Corp.).

Plate boundary study in the West Indies.—L. E. Garrison, J. V. A. Trumbull, M. F. Marlow, R. G. Martin, Jr., A. K. Cooper, and R. L. Immel made approximately 5,800 km of geophysical survey track in the Atlantic and northeastern Caribbean as part of the Geological Survey's participation in IDOE. Preliminary examinations of the seismic reflection profiles show an interesting comparison between the Muertos Trough, which separates the Greater Antilles from the Venezuelan Basin, and the northeastern part of the Puerto Rico Trench between the Atlantic floor and the Lesser Antilles. In both instances oceanic sediment and basement reflectors dip beneath the flanks of the bordering insular ridges and can be traced for several kilometers landward.

Previous investigators have postulated that Atlantic crust is being thrust under the Caribbean crustal plate in the Puerto Rico Trench on the basis of magnetic evidence of westward seafloor spreading in the Atlantic and seismological evidence of a Benioff zone dipping west beneath the island arc. Although the reflection profiles reveal an almost identical structural framework in the Muertos Trough, a case for underthrusting is more difficult to make in the light of relative motions of plates in the region and a history of low seismicity along the trough. More detailed studies, however, indicate a good possibility that Caribbean crust was sliding beneath the Greater Antilles during the period from middle Oligocene to Pliocene.

In the Puerto Rico Trench, all traverses made south of lat 19°N. show oceanic layers passing beneath the broad lower slope of the Lesser Antilles arc while crossings north of lat 19°N. do not record oceanic horizons beneath the landward wall of the trench. It would thus appear that the relative plate motion between the Atlantic (North American) and Caribbean plates undergoes a transition from westward underthrusting to east-west stike-slip motion in this vicinity.

PACIFIC CONTINENTAL MARGIN

Offshore extension of Rose Canyon fault.—Subbottom acoustic reflection profiles, obtained in November 1970 on a cruise of the RV *Polaris*, provide definite evidence of a major fault about 7 km offshore from Oceanside in southern California. G. W. Moore reports that the fault is a northern extension of the Rose Canyon fault of the San Diego area. The offshore fault locally offsets the sea floor and can be traced some 50 km northwestward from La Jolla along the California coast.

Mineral resources of offshore southern California.—D. S. Gorsline (Univ. of Southern California) reports that, despite variations in texture, almost all phosphorite nodules from off southern California and New Zealand exhibit characteristics best accounted for by their being erosionally derived from texturally similar bedded deposits. Submerged areas where phosphorites occur were generally exposed due to tectonic activity or lowering of Pleistocene sea level as can be shown by accepting a 100-m lowering or by noting presence of submarine terraces and subaerially formed topographic features which occur near or below phosphatic deposits. That nodules themselves have undergone erosion is indicated by fracturing, rounding, and truncation of internal structures and components. Even the protuberances, which in part give some nodules their unusual shapes, can be seen in polished section to be features formed by erosion. Associated materials such as rounded gravels and coarse relict sands are consistent with the nodules being reworked. Pholad borings, vugs, and a weathering rind further indicate shallow water or exposure. The variety of lithologic types associated with phosphorites and significant textural variations in nodules at a single station can be explained by an erosional and transported origin.

Ventura-Oxnard plain offshore region.—H. G. Greene reports that the Ventura, Calif., offshore area is extensively covered with Quaternary sediment; a maximum thickness of over 4,000 ft of Quaternary sediment is deposited in the area, and most of this consists of water-bearing material. Total areal

extent of the offshore ground-water basins is over 475 sq mi and has an average thickness of about 1,200 ft. Offshore drill-hole data suggest that about half of this area contains fresh water. Fresh water aquifers—identified by their relationship to unconformities within the Pleistocene—have been traced throughout the investigation area and crop out along the walls of the submarine canyons and along the landward slopes of Santa Barbara and Santa Monica Basins. A detailed, vertical, continuous temperature-salinity profile survey of Hueneme Canyon was made in 1971 during a time of maximum recharge of the aquifers. Stations were based on the interpretation of seismic records and positioned where aquifers appeared to crop out along the canyon's walls. The fact that no anomalous salinity readings were obtained at these stations suggests that the aquifers were not fully recharged and did not have a large enough hydraulic head to force fresh water out into the ocean.

Monterey Bay, California.—A fault map by H. G. Greene from the interpretation of seismic reflection profiles of Monterey Bay shows two active fault zones, the Monterey Bay and Carmel Canyon. These two zones impinge upon each other in northern Monterey Bay. At their intersection many small to medium magnitude earthquakes have occurred. Recent creep studies along the San Andreas fault by R. O. Burford and results of the Monterey Bay investigation have shown that the Monterey Bay fault zone is part of the San Andreas fault system. The Carmel Canyon fault zone also appears active and connects with the San Gregorio fault to the north and the Palo Colorado fault to the south.

Extensive dredging along the walls of Monterey Canyon and adjacent slope areas has shown that a previously undetected outcrop of the Purisima Formation (Pliocene) extends for over 5 mi along the outer southern rim of Monterey Canyon. A large molluscan fossil assemblage has been collected from this area and seems to correlate with the same fauna facies that crops out in the sea cliffs of Capitola Beach, 10 mi to the north. An abundant collection of *Astarte*, a cool temperate- to cold-water pelecypod, has been recovered along the upper walls of an unnamed tributary to Monterey Canyon, approximately 6 mi SW of Monterey. This find is significant zoogeographically because it has not been previously reported as a fossil or modern specimen south of Puget Sound. The occurrence of *Astarte* in the Pleistocene assemblage suggests water temperature substantially cooler than occurs at this latitude today.

Geophysical studies of the Farallon Ridge.—Reflection profiles across the central California continental margin, taken by E. A. Silver and J. R. Curray (1971), have delineated the northern extension of the granitic Farallon Ridge to its termination west of Point Arena. A dredge haul from another ridge northwest of Point Arena yielded weakly metamorphosed graywacke. Franciscan-type basement probably underlies the continental margin north of Point Arena. The northern end of the Farallon Ridge may mark the end of the Salinian block, thus supporting a total offset of 600 km along the San Andreas fault.

Heavy metals in Oregon shelf sands.—Analyses by L. D. Kulm (Oregon State Univ.) of opaque oxides in offshore and onshore heavy mineral concentrates from the coast of southern Oregon suggest the following: (1) Chromium is a matrix metal of chrome spinel and is diadochic into magnetite, (2) iron appears in all opaque oxides and in increasing amounts with increasing susceptibility, (3) titanium is a matrix metal in ilmenite, and diadochic into chrome spinel and magnetite, (4) nickel and ruthenium are diadochic into and correlated to the spinel structure; that is, to chrome spinel and magnetite, (5) osmium appears to be correlated to chromium, and (6) zinc is limited to spinel structure.

The energy parameter of the octahedral site preference offers an explanation for the observed distribution of platinum group metals in spinel minerals from this investigation. Chrome spinel from Oregon had twice the concentration of ruthenium and one-third the amount of osmium as similar Uralian chromite deposits. Ruthenium also occurs in significant quantities in magnetite.

Wave swash versus backwash in the transport of beach sand.—H. E. Clifton, R. L. Phillips, and A. G. McHendrie report that a device designed to sample the sand transported at different heights above a beach surface during wave swash and backwash has proved highly successful. Preliminary analysis of samples demonstrates that much more sand is carried in suspension in wave swash than in backwash where bedload transport strongly predominates. Most of the sand in transit during swash is picked up where the incoming wave interacts with the backwash of the previous wave. Heavy minerals appear to be preferentially carried in suspension and to be selectively left behind in bedload transport. This observation explains the concentration of heavy minerals commonly found on the upper part of many beaches.

Pre-Tertiary rocks on the west side of the Olympic Peninsula.—Lower and middle Eocene tholeiitic basalt pillows and breccia, previously considered the oldest rocks in the Oregon and Washington Coast Range and on the Olympic Peninsula, have been interpreted as oceanic basalt (Snavely and others, 1968). Recent reconnaissance studies, however, along the Pacific Coast of the Olympic Peninsula by P. D. Snavely, Jr., and N. S. MacLeod indicate that older igneous and sedimentary rocks crop out in the seacliff and on small islands at Point of Arches, 10 mi south of Cape Flattery. This locality was briefly described by Arnold (1906). The main mass of these rocks is a sheared, uralitized, and locally gneissic diorite that includes hornblendite, aplite, and quartz segregations. The diorite is assigned a Middle Jurassic or older age on the basis of a potassium-argon hornblende age of 144±2.4 m.y. determined by R. W. Tabor. Marine sedimentary and volcanic rocks of probable pre-Tertiary age are in depositional contact with the diorite. Hornblende from an altered dacitic sill that intrudes these sedimentary and volcanic rocks has a 59±3 m.y. potassium-argon age (Paleocene). The pervasive metamorphism of the diorite and alteration of the dacitic sill indicate that the

actual ages may be older than the measured potassium-argon ages. The pre-Tertiary rocks are unconformably overlain by upper Eocene marine conglomerate, sandstone, and siltstone.

The occurrence of these pre-Tertiary rocks within the area formerly thought to be underlain only by lower Eocene oceanic basalt and younger sedimentary and volcanic rocks is enigmatic. The Point of Arches pre-Tertiary igneous and sedimentary rocks may correlate with rocks exposed on Vancouver Island. The Leech River fault, which juxtaposes pre-Tertiary metasedimentary and plutonic rocks on the north with the Metchosin volcanics (Eocene) to the south (Clapp, 1912; Muller, 1971), may extend along its mapped trend southwestward from Vancouver Island onto the southwestern part of the Washington continental shelf as suggested on the basis of magnetic data by Stacey and Steele (1970). The Leech River fault and the pre-Tertiary sedimentary and igneous rocks that occur on its north side may have been offset southeastward to their present position by several northwest-trending faults mapped between Point of Arches and Cape Flattery. Alternatively, but accepting the same postulated extension of the Leech River fault, the pre-Tertiary rocks may have been emplaced by gravity sliding from a source north of the fault.

GULF OF ALASKA, BERING AND BEAUFORT SEAS

Deep sea drilling in the Gulf of Alaska.—R. E. Von Huene reports that deep-sea drill cores recovered off Kodiak revealed younger ages and higher rates of sedimentation than previously estimated (Von Huene and others, 1971). Grey-mud turbidites (middle Pliocene to Holocene) that compose more than 75 per cent of the first 270 m in hole 178 were deposited rapidly (160 m/m.y.) on the Alaska abyssal plain. Abundant ice-rafted debris in the mud extends back to middle Pliocene time. Below the grey mud the section accumulated at about one-tenth the rate and consists of interbedded mud, diatomaceous sediment, and silt and sand turbidites. Sediments of similar lithology fill the trench at site 180. From the cores it would be difficult to differentiate by lithology the lower section in hole 178 from the trench fill recovered in hole 180. The overall rate of sedimentation at the present trench axis is 1,000 m/m.y. on the basis of the maximum age (0.9 m.y.) of trench-filling sediment.

On the steep 2,000-m ridge of the lower continental slope (hole 181), the drill first penetrated a sequence of deposits 169 m thick, similar to those normally found on the lower continental slope. Drilling then became difficult because the bit suddenly entered very hard, deformed mudstone which also contained abundant ice-rafted lithic clasts. This sediment, which yielded Pleistocene diatoms, appears to have undergone extensive dewatering. Its original site of deposition is difficult to recognize because the sediments recovered from the abyssal plain, the trench, and the lower slope cannot as yet be differentiated with confidence by their lithologies. However, its lithology is significantly different from the pebbly muds and sands that accumulated on the upper continental slope.

The major conclusion from these data is that steep slopes of acoustic basement commonly seen in seismic records across the landward wall of the Aleutian Trench need not be composed of older lithified sediment but may instead be young trench or abyssal plain sediment that has been highly deformed.

Deep sea drilling in the Bering Sea.—D. W. Scholl reports that deep-sea drilling at eight sites in the Bering Sea during the summer of 1971 has produced a number of significant results including the findings that (1) a thick mass of lower Tertiary debris, an archipelagic apron(?), accumulated at the base of the Aleutian Ridge prior to the late Miocene, (2) middle and lower upper Miocene deposits are chiefly mudstone formed by the in situ lithification of undeformed terrigenous mud, (3) upper Miocene and Pliocene deposits are typically diatom ooze that accumulated at the astonishingly high rate of 100 m/m.y., (4) in the Pleistocene, especially the latter half, layers of size-graded silt and sand (turbidites) spread over the abyssal floor of the Bering Sea, burying older sequences of diatom ooze or pelagic mudstone, (5) beginning about 3 m.y. ago, volcanism along the Aleutian Ridge and in Kamchatka became exceptionally intense and has continued to the present, and (6) also about this time ice-rafted(?) debris began to accumulate over much of the Aleutian-Bering Sea region (Scholl and others, 1971).

Paleo-oceanography of Bering Sea.—Study by D. M. Hopkins and R. W. Rowland of Pleistocene fossil mollusk faunas from the Alaskan and Siberian coasts of the Bering Sea provides the basis for a reconstruction of general features of the circulation during the Pelukian (Sangamon) and Kotzebuan (pre-Illinoian) transgressions (Hopkins, 1972; Hopkins and others, 1972). During Sangamon time, as at present, circulation was dominantly northward through Bering Strait. The circulation, however, was dominated by a current that brought warm Pacific water into the Bering Sea through the pass between the Komandorskiye Islands and the Near Islands rather than through the eastern Aleutians as at present. After touching the Kamchatka coast, the current passed diagonally across the Bering Sea to the delta of the Yukon River and then was deflected northward toward Bering Strait.

During Kotzebuan time, cold Arctic water passed southward through the Bering Strait and then followed the Siberian coast to Kamchatka. Relatively warm Pacific water passed northward through the eastern Bering Sea but then was deflected southwestward and was entrained with Arctic water moving southward through Anadyr Strait. This alteration of the ocean circulation was radical and must have been accompanied by a more intense flow of Atlantic water into the eastern Arctic Ocean.

Trace metal content of surface relict sediments and displacement of northern Bering Sea Holocene sediments.—C. H. Nelson reports that in addition to potentially economic deposits of gold and tin in the northern Bering Sea, natural anomalies of potentially hazardous (Hg, Cu, Cr) trace metals have been detected. The highest anomalies (1.3 ppm Hg) occur

locally on beaches near natural deposits, and lower anomalies (0.25–0.5 ppm Hg) occur scattered throughout surface and near-surface relict sediments covering the floor of the northern Bering Sea. These relict sediments consist of limnetic clayey silt and peat overlain by transgressive beach facies composed of thin lenses of coarse sands and gravels and nearshore sand layers.

Despite the great influx of Yukon River sediment, generally only a thin layer (about 0.2 m) of the distinctive river silt covers the relict facies in central and southern Norton Sound near the present Yukon Delta. Occurrence of the thin Holocene deposits near the river mouth, of mainly relict sediments in northern Bering Sea north of St. Lawrence Island, and of several meters of Holocene sediment in the Chukchi Sea permits speculation that large volumes of Yukon sediment are periodically being flushed from Norton Sound. Apparently the amphidromic tidal system, storm surges, and strong northerly currents are responsible for sweeping the Yukon sediment from the northern Bering Sea into the Chukchi Sea.

Environmental studies in the eastern Chukchi Sea.—Geologic sampling in the eastern Chukchi Sea by P. W. Barnes (1971a, b) and J. V. A. Trumbull has further defined the sediment distribution pattern and has outlined a particulate transport process for the region.

Water turbidity, bottom sediments, and the associated current and water mass regime of the northwest coast of Alaska during the fall of 1970 suggest that fine material is transported northward from the Bering Straits through the eastern Chukchi Sea to the Arctic Ocean. Fine particulate matter moves near the bottom along the eastern part of the trough between Herald Shoal and the Alaska coast. Over shallower parts of the shelf, freezing and storm activity circulate and mix suspended matter vertically throughout the water column during the fall.

The coincident association of a muddy bottom with the zone of highest turbidity indicates sedimentation from northward-flowing waters. The lack of pebbles in these muds indicates that ice rafting is not, at present, an important mode of sediment deposition here.

Considerable interaction between the benthos and bottom sediments is apparent. Materials presumed to be of both modern and relict or residual origin show negligible current-produced sedimentary structures. Most turbation can be ascribed to the benthic activity of a varied fauna consisting of pelecypods, amphipods, echinoids, worms, and even walruses.

Associated geochemical studies by K. W. Leong and V. E. Swanson show no evidence of anomalous values of selected heavy metals or hydrocarbons (Barnes and Leong, 1971). The low concentrations of copper, lead, zinc, and mercury and somewhat higher values of arsenic all appear to be related to sediment type. The unique composition of the hydrocarbons suggests that arctic sediments may differ significantly from those of lower latitudes.

Marine geological studies of the inner Beaufort Sea shelf.—Erk Reimnitz reports that high resolution sparker surveys in the shelf region and lagoons around Prudhoe Bay show the thickness and depths of several distinct sedimentary units overlain by a thin section of probable Holocene marine sediments. In an attempt to correlate depths of acoustic reflectors with published marker horizons onshore, the best fit is obtained when water velocity is multiplied by a factor of three, a correlation suggesting that much of the section penetrated below the sea is frozen permanently. Several other lines of evidence, including measured sediment temperatures of as low as −3°C near the sea floor, support this assumption. A substantial bed of sand and gravel appears to be masked by a thin and patchy Holocene sediment cover in some areas at shallow water depth.

A broad, shallow bench around the Colville River delta front coincides in depth with the thickness of the seasonal fast ice and has been thought to represent an area of sediment bypassing, related to the mechanism of ice breakup (Reimnitz and Brader, 1972). All the inner shelf is affected by ice gouging which reworked the upper 2 to 3 m of sediments. A limited number of under-the-ice observations indicates that little sediment is incorporated and rafted away, but grounding ice enhances suspended sediment transport by stirring the bottom and by affecting the current flow regime.

GENERAL OCEANIC AND INTERNATIONAL STUDIES

Mineral resources of the sea.—A report entitled "The Sea: Mineral resources of the sea" was prepared by F. H. Wang (1971) in cooperation with the United Nations Secretariat as an updated supplement to the previous U.N. publications on this subject. The latest report (in English, French, Spanish, and Russian) was presented by the U.N. Secretary-General to the Economic and Social Council, the General Assembly, and the U.N. Seabed Committee to study the international aspects of ocean exploration and mineral development, jurisdictional problems, possible effect of deep-sea mineral exploitation in the marine environment, and possible impact on world markets and economy. It describes the past 2 years' significant subsea mineral discoveries and marine geologic findings, steady progress of offshore petroleum production in increasingly deeper waters, the latest breakthroughs and new trends in offshore petroleum technology (Wang, 1971) and ocean mining technology, and applications of these technologies to other new marine tasks.

Ores in the Red Sea.—A report on shipboard geochemical surveys of the Red Sea bottom was prepared by F. T. Manheim. Spectrographic analyses of sediments in the vicinity of the hot brine zones in the central part of the Red Sea revealed metal anomalies, reaching 2 percent copper and zinc, in strata older and farther from the known metal-rich deposits than previously realized. The work was done in conjunction with a cruise led by D. A. Ross (WHOI) in the spring of 1971. The cruise was supported by the Saudi Arabian Government through the joint program with the USGS.

Deep-sea sediment pore fluids.—Irving Friedman reports that

the isotopic composition of the ancient oceans can be approximated from the deuterium content of pore waters squeezed from JOIDES deep-sea cores. A significant difference in deuterium-hydrogen ratio from samples as closely spaced as 0.5 in a single core of Pleistocene age shows that diffusion of water vertically in the core is greatly reduced over that in an open system. The results also show that most of the compaction probably takes place in the first few centimeters of burial and little thereafter.

Sulfur content of submarine basalt.—J. G. Moore and B. P. Fabbi (1971a, b) report that sulfur analyses by X-ray fluorescence give an average content of 107 ppm for nine samples of fresh subaerially erupted oceanic basalt and 680 ppm for 38 samples of submarine-erupted basalt. This difference is the result of retention of sulfur in basalt quenched on the sea floor and loss of sulfur in subaerially erupted basalt by degassing at the surface. The outer glassy part of submarine-erupted basalt contains 800±150 ppm sulfur, and this amount is regarded as an estimate of the juvenile sulfur content of the basalt melt from the mantle. The slower cooled interiors of basalt pillows are depleted in sulfur relative to the rims owing to degassing and escape through surface fractures. Available samples of deep-sea basalts do not indicate a difference in original sulfur content between low-potassium tholeiite, Hawaiian tholeiite, and alkali basalt.

The depletion of sulfur may account for the common association of native copper deposits with subaerial basalt and massive sulfide with ancient submarine basalt. In fresh material, the sulfur content provides a method of distinguishing pillow basalt fed by a subaerial flow which crossed a shoreline (low sulfur) from pillow basalt fed from a relatively deep subaqueous vent (high sulfur).

Precision of Pliocene coccolith stratigraphy.—Coccolith-based zonation of the Pliocene in deep-sea sediment from low to middle latitude permits division of this short epoch into intervals averaging only 500,000 yr. Seven subzones can be recognized by appearances, acmes, or disappearances of a group of species that show the same general succession in DSDP cores from the Mediterranean Sea, Atlantic Ocean, Caribbean Sea, and equatorial Pacific Ocean. J. D. Bukry (1972) reports a sequence of appearances (*), acmes (A), or disappearances (†) from early to late Pliocene that includes the following: *Triquetrorhabdulus rugosus* (†), *Ceratolithus amplificus* (*), *C. rugosus* (*), *C. tricorniculatus* (†), *Sphenolithus neoabies* (A), *Discoaster asymmetricus* (A), *D. tamalis* (*), *D. variabilis decorus* (*), *Reticulofenestra pseudoumbilica* (†), *Sphenolithus neoabies* (†), *Discoaster variabilis decorus* (†), *D. tamalis* (†), *D. asymmetricus* (†), *D. surculus* (†), *D. pentaradiatus* (†), *Cyclococcolithina macintyrei* (A), *Discoaster brouweri* (†). The utility of this general sequence in widely separated areas and in the short geologic timespan represented by these events demonstrates a high degree of synchroneity for the record of genetic changes in coccoliths in the Pliocene ocean.

ESTUARINE AND COASTAL HYDROLOGY

Estuarine water quality

Although there are many variables that can be used as measures of estuarine water quality, the most common are salinity, oxygen, BOD, and COD. Knowledge of longitudinal salinity movement in an estuary and of salt incursion into aquifers is important to water users located in the transition zone between fresh and salt water. Oxygen, BOD, and COD are important measures of the effects and degree of organic and industrial waste loading, especially in an estuary which functions as an entrapment basin.

During the low-flow periods of 1969 and 1970, J. F. Santos and J. B. McConnell collected COD and BOD data for the Duwamish River estuary and the Green River of the State of Washington. The data showed the organic content in the estuary and river to be low. COD of fresh-water samples ranged from 3 to 14 mg/l. COD of salt-water samples was generally less than 85 mg/l; however, the concentrations near 85 mg/l were caused by chloride interference. Five-day BOD values of both fresh- and salt-water samples ranged from 0.4 to 3.8 mg/l.

Studies by D. C. Hahl showed that, in general, the estuaries of Texas are characterized by DO at and above saturation, 5-day BOD values less than 5.0 mg/l, Secchi disk transparencies of 30 to 90 cm, ammonia (reported as nitrogen) generally less than 0.4 mg/l, nitrite (reported as nitrogen) generally less than 0.1 mg/l, and total phosphorus (reported as phosphate) generally less than 0.7 mg/l.

Insecticide concentrations in sediment in the Texas estuaries, according to Hahl, were as high as 26 mg/l DDT, 52 mg/l DDE, and 21 mg/l DDD, whereas the largest concentrations of these constituents in water were 0.61, 0.02, and 0.00, mg/l, respectively. Herbicides were almost nonexistent in sediments and were in very low concentrations in water. For example, 2,4-D concentration was 0.00 mg/l in sediment and 0.25 mg/l in water.

Water-budget studies to be used for development of planning models were made by Hahl on four Texas estuaries. The maximums recorded for flow and velocity through one of the passes to the Gulf of Mexico were 266,000 cfs and 8.31 fps, respectively.

Measurements by J. R. Williams and G. D. Tasker of salinity, fresh-water discharge, and tide range in the North and South Rivers estuary in southeastern Massachusetts for the period July 1970 to July 1971 indicated that average salinity at any point in the estuary is a function of fresh-water discharge. Short-period changes in salinity are related to short-period changes in fresh-water flow and also to short-period changes due to lunar tides as well as to wind-induced changes in tidal height. Tide range at the estuary mouth is 8.5 ft, and tide reversal is detectable for a distance of 14 mi upriver.

Estuarine metabolism

R. L. Cory has operated a nine-parameter water- and weather-quality station at the Rhode River estuary, Edgewater, Md., since April 1970. Visual inspection of annual graphs of percentage saturation of oxygen reveal much about the biological metabolism of the system. In March a phytoplankton bloom, indicated by oxygen supersaturation, is followed by a zooplankton increase which causes an oxygen deficit. In May a larger phytoplankton bloom develops, an excess of organic carbon is produced, and oxygen saturation is above 120 percent. Summer is characterized by large daytime production and nighttime respiration causing the system to fluctuate from 30- to 215-percent oxygen saturation. In late September, daily production diminishes and continued high respiration drives the system to subsaturation. During autumn, fresh-water runoff increases and temperatures drop; an autumn phytoplankton bloom develops and persists until ice covers the estuary and, by limiting light, causes the net production to drop to zero. Metabolism estimates made from analysis of diurnal oxygen curves verify the visual interpretations from the percentage-saturation curve. Estimates of daily net production range from 0.0 in midwinter to about 9.6 g/m^2 of oxygen in midsummer while respiration ranges from 0.3 in winter to 6.8 g/m^2 of oxygen in summer.

Estuarine hydraulics and mathematical models

C. R. Goodwin reported that data collection of bathymetric, seismic, photogrammetric, meteorological, biochemical, geological, and hydraulic features at Tampa Bay, Fla., is nearing completion. These data have been collected to verify a two-dimensional digital model of Tampa Bay. Preliminary results show that wind shear forces on the bay surface are, at times, of the same magnitude as the tide-producing forces. Stereocompilation has been successfully applied for determining bay-bottom configuration to a depth of about 15 ft below the water surface. A successful first application of automatic digital positioning and bathymetric systems transported by boat was made over the entire bay area. More than 10,000 separate water-quality determinations provide benchmark information for model development and management of the bay.

The fitting of a mathematical model, developed by H. B. Fischer, to the Duwamish River estuary, Wash., was begun this year. Emphasis has been on the circulation part of the model. Model salinity is the criterion used for checking the model against the prototype. To date, fairly reasonable comparisons have been recorded of model salinities versus prototype salinities for selected times, depths, and longitudinal positions.

S. L. Laskowski compared peak tidal stages in bays and estuaries to those at the ocean front in five communities along the New Jersey coast. Comparisons were made by leveling to numerous high-water marks and by analyzing records of tide-gage stations.

At Bay Shore in Barnegat Bay, Laskowski found the stages of mean annual high tides to be about 2 ft less than the corresponding stages at the ocean front and the peak stages of unusually high tides to be as much as 3½ ft less than those at the ocean front. In several estuaries at Manasquan he found peak stages to be about 1 ft lower than those at the ocean front. On the other hand, limited data in the upper estuary of Shark River at Belmar indicated that peak stages were about 1 ft higher than the corresponding stages at the ocean front. The differences in the relationships were attributed primarily to the size and shape of the inlets and to the wind direction.

Geological structure and estuaries

R. A. Gardner studied the structural features of shallow rocks which act as the principal storage area of fresh water in the Beaufort, S.C., area. The goal of the study was to gain an understanding of the relationships between the aquifer and the overlying estuary. The investigation was primarily geophysical and consisted of borehole surveying and reflection seismic surveying. Some geological and hydrological data were collected to aid in analysis and interpretation of the geophysical data. Interpretation of the data indicated that the major structural feature of the study area is a ridge trending in a northeast-southwest direction. These data are interpreted as evidence of the existence of the Yamacraw Ridge in the Tertiary rocks.

Other significant features observed include buried stream channels, some internal sedimentary structures, and a possible fault. Sinks, caverns, or solution valleys (karst) were not observed in the seismic records of the subsurface structure. Occasional deep submarine holes in the study area show no evidence of collapse in the associated rocks.

Dye-tracer simulation test in Battery Creek, South Carolina

At the request of the South Carolina Water Resources Commission, F. A. Kilpatrick and E. L. Meyer performed a dye-tracer simulation test in Battery Creek near Beaufort, S.C., at the proposed location of a new sewage-plant outfall. The test involved the continuous injection of Rhodamine WT dye for two tidal cycles into the oscillating tidal flow of Battery Creek. The dispersed dye cloud was periodically sampled at selected points for 17 days. Utilization of this data and the superposition principle provided both qualitative and quantitative evaluation of the potential movement and concentration buildup of sewage effluents into the estuary.

MANAGEMENT OF NATURAL RESOURCES ON FEDERAL AND INDIAN LANDS

The Conservation Division is responsible for carrying out the U.S. Geological Survey's role in the management of the

mineral and water resources on Federal and Indian land including the Outer Continental Shelf; that role includes, in particular, the conservation, evaluation, and development of the leasable mineral resources and waterpower potential of these areas. Primary functions are (1) mapping and evaluation of mineral lands, (2) delineation and preservation of potential public-land reservoir and waterpower sites, (3) promotion of orderly development, conservation, and proper utilization of mineral resources on Federal lands under lease, (4) supervision of mineral operations in a manner to assure protection of the environment and the realization of a fair value from the sale of leases and to obtain satisfactory royalties on mineral production, and (5) cooperation with other agencies in the management of Federal mineral and water resources.

MAPPING AND EVALUATION OF MINERAL LANDS

The organic act creating the U.S. Geological Survey gave the Director the responsibility of classifying and evaluating the mineral resources of the public domain lands. There are about 250 million acres of land for which estimates of the magnitude of leasable mineral occurrences have been only partly made. Such appraisals are needed to reserve valuable minerals in the event of surface disposal and to assist in determining the extent of our mineral resources. Estimates are based on data acquired through field mapping and the study of available geologic reports in addition to spot checks and investigations made in response to the needs of other Government agencies. As an aid to this assessment for certain minerals, guidelines have been prepared setting forth limits of thickness, quality, depth, and extent of a mineral occurrence that are necessary before land is considered to be mineral land.

Classified land

As a result of U.S. Geological Survey investigations, large areas of Federal land have been formally classified "mineral land." Mineral land classification complements the leasing provisions of the several mineral leasing laws by reserving to the Government, in disposals of public land, the title to such energy resources as coal, oil, gas, oil shale, asphalt and bituminous rock, and such fertilizer and industrial minerals as phosphate, potash, sodium minerals, and sulfur.

These reserved minerals on public lands are subject to development by private industry under the provisions of the Mineral Leasing Act of 1920. All minerals in acquired lands and on the Outer Continental Shelf are subject to development under comparable acts.

Geologic maps and studies developed to assist in mineral land classification are published in the regular Geological Survey publications series.

During fiscal year 1972, more than 87,000 acres of land were formally classified "coal land," and about 1,300 acres were classified "phosphate land" in the States of California, Utah, Alaska, and Wyoming, mainly as a result of the leasable mineral mapping program of the Geological Survey. Most of these lands were previously withdrawn to prevent alienation of the leasable minerals until an examination and classification could be made. More than 21,000,000 acres remain withdrawn for coal; 1,600,000 acres, for phosphate; and 9,000,000 acres, for potash.

Producing oil and gas structures

By the provisions of the Mineral Leasing Act of 1920, the Secretary of the Interior is authorized to grant to any applicant qualified under the act a lease to prospect for oil or gas on any part of the mineral estate of the United States that is not within any known geologic structure of a producing oil or gas field. Lands within such known structures are leased to the highest bidder. During fiscal year 1972, almost 240,000 acres of onshore Federal land were determined to be in known geologic structures.

WATERPOWER CLASSIFICATION—PRESERVATION OF RESERVOIR SITES

The objective of the waterpower classification program is to identify, evaluate, and segregate from disposal or adverse use all reservoir sites on public lands which have significant potential for future development. Such sites are an increasingly scarce and valuable natural resource. U.S. Geological Survey engineers study maps, photographs, and waterflow records to discover potential damsites and reservoir basins. Selected sites are mapped, and engineering and geologic studies are made to determine whether lands qualify for formal classification as valuable sites. Such resource studies provide land-administering agencies with information basic to management decisions on land disposal and multiple use. Previous classifications are reviewed as new data become available; if no longer considered suitable for reservoir development, land is released for return to the unencumbered public domain for other possible disposition. During fiscal year 1972 about 125,000 acres of previously classified lands were released, and the review program was carried on in 19 river basins in the Western States and Alaska.

The Geological Survey conducts a limited specialized mapping program to aid in water-resources classification of areas not covered by maps of standard accuracy in the topographic quadrangle series. River basins are mapped at a scale of 1:24,000, and lake bottoms are contoured by precise sounding surveys. During fiscal year 1972, fieldwork was completed on damsite surveys in Washington and Oregon, and maps of several dam and reservoir sites in Alaska, Montana, and Washington were published.

SUPERVISION OF MINERAL LEASING

Supervision of competitive and noncompetitive leasing activities to develop and recover leasable minerals in deposits on Federal and Indian lands is a function of the U.S. Geological Survey, under delegation from the Secretary of the Interior. It includes (1) geologic and engineering examination of applied-for lands to determine whether a lease or a permit is appropriately applicable, (2) approval of operating plans, (3) inspection of operations to insure compliance with regulations and approved methods, and (4) verification of production and the collection of royalties. (See table 1.)

Before recommending a lease or permit, Geological Survey engineers and geologists consider the possible effects upon the environment. Of major concern are the esthetic value of scenic and historic sites; the preservation of fish and wildlife and their breeding areas; and the prevention of land erosion, flooding, air pollution, and the release of toxic chemicals and dangerous materials. Consideration is also given to the amount and kind of mining-land reclamation which will be required.

Louisiana Outer Continental Shelf lease sale for oil and gas

A sale of Federal Outer Continental Shelf leases for oil and gas was held in November 1971. Eighteen tracts covering 55,872 acres were offered. High bids worth $96,304,522 were accepted for 11 of the tracts. The highest accepted bid was $18,005 per acre. Geological Survey engineers, geologists, and geophysicists prepared evaluation studies and reports leading to minimum acceptable bids for each lease block offered.

COOPERATION WITH OTHER FEDERAL AGENCIES

The U.S. Geological Survey acts as a consultant to other Federal agencies in land-disposal cases. In response to their requests, determinations are made as to the mineral character of specific tracts of Federal lands under their supervision which are proposed for sale, exchange, or other disposal. More than 13,000 such reports were made during fiscal year 1972.

Table 1. *Mineral production, value, and royalty for fiscal year 1972*[1]

Lands	Oil (barrels)	Gas (thousand cubic feet)	Gas liquids (gallons)	Other[2] (tons)	Value (dollars)	Royalty (dollars)
Public	176,291,000	994,370,000	626,571,000	29,831,000	$ 939,456,000	$ 98,977,000
Acquired	9,230,000	38,378,000	1,914,000	563,000	96,982,000	7,108,000
Indian	29,828,000	124,797,000	50,079,000	18,318,000	169,775,000	20,828,000
Military	564,000	21,696,000	22,215,000	–	6,849,000	1,110,000
Outer Continental Shelf	424,499,000	2,774,904,000	1,630,445,000	1,733,000	2,192,090,000	359,175,000
Naval Petroleum Reserve No. 2	2,802,000	4,293,000	19,244,000	–	11,417,000	1,505,000
Total	643,214,000	3,958,438,000	2,350,468,000	50,445,000	3,416,569,000	488,703,000

[1] Estimated in part.
[2] All minerals except petroleum products; includes coal, potassium, and sodium minerals and so forth.

GEOLOGIC AND HYDROLOGIC PRINCIPLES, PROCESSES, AND TECHNIQUES

EXPERIMENTAL GEOPHYSICS

HEAT FLOW

Heat flow and surface radioactivity in Australia

J. H. Sass (USGS) and J. C. Jaeger (Australian Natl. Univ.) have obtained new heat-flow and heat-production data from 19 sites in Australia. A preliminary interpretation confirms low-to-normal heat flow in the old (≈2.500 m.y.) shield but supports previous indications of high heat flow (≈2 μcal $cm^{-2}sec^{-1}$) in the "Proterozoic" Shield. At some of the latter sites, this high flux coincides with very high near-surface radioactivity. At others, radioactivity is low to normal, but studies of the deep structure of electrical conductivity by M. W. McElhinny and others (1972) and of seismicity by J. R. Cleary and D. W. Simpson (1971) support the interpretation of high heat flow from the mantle arising from renewed tectonic activity during the Cenozoic Era.

Paleoclimatic implications of uniform heat flow in a deep hole in the Canadian Shield

Temperature measurements in a deep hole in granite near Flin Flon, Manitoba, Canada, by T. H. Moses, Jr., determinations of thermal conductivity by R. J. Munroe, and radioactivity measurements by C. M. Bunker were analyzed by J. H. Sass and A. H. Lachenbruch (USGS) and A. M. Jessop (Earth Physics Br., Dept. Energy, Mines, and Resources, Ottawa, Canada) (1971). The mean heat flow and radioactive heat production of 1.01 μcal $cm^{-2}sec^{-1}$ and 2.1×10^{-13} cal $cm^{-3}sec^{-1}$ respectively were consistent with other observations of these quantities in the stable interior of North America. The uniformity of heat flow to a depth of nearly 3 km in this region of Pleistocene glaciation casts doubt on some of the more extreme Pleistocene climatic models which resulted in large corrections to observed heat flows.

Heat flow and radioactivity in South Greenland

Heat flow and surface radioactivity were determined at two sites in the Precambrian Shield of South Greenland by J. H. Sass (USGS), B. L. Nielsen (Geol. Survey of Greenland), H. A. Wollenberg (Lawrence Berkeley Lab.) and R. J. Munroe (USGS) (1972). At Ivigtut, heat flow (q) averaged 1.0 hfu (μcal $cm^{-2}sec^{-1}$), and the radioactive heat production (A_0) averaged 5.5±1.5 heat generation units (10^{-13} cal $cm^{-3}sec^{-1}$) which is consistent with other q and A_0 pairs from the Canadian and Australian Shields. Near the northwestern edge of the Ilimaussaq alkali intrusion, however, q averages only 0.9 hfu for a mean A_0 of over 20 heat generation units. The latter observation implies that, unless heat flow from the mantle is inexplicably low in this part of Greenland, (1) the highly radioactive part of the intrusion is quite thin (≈1 km) and (2) the underlying crustal rocks contain very little radioactivity.

Anomalous heat flows mapped by snowfall calorimetry

Mapping by D. E. White in Norris Geyser Basin of Yellowstone Park was in part focused on tree-line bounding areas inside of which near-surface ground is too warm for lodgepole pines to grow. New data utilizing White's snowfall calorimetry method (White, 1969) for mapping contours of total heat flow indicate that the mapped tree lines are approximately coincident with the 1,000-hfu contour, about 700 times average worldwide conductive heat flow. First efforts were made to apply the method to anomalies of lower intensity, using multiple snowfalls and longer time periods. Two mapped contours of ≈450 and 270 hfu are in forested areas and bracket results from USGS research drill hole Y-9 which shows a near-surface conductive heat flow of about 225 hfu. The agreement is satisfyingly close, and the discrepancy is being studied.

ROCK MAGNETISM

Decrease in geomagnetic secular variation with geologic time

Angular dispersion of virtual geomagnetic poles (VGP) paleomagnetically recorded in many sequences of lava flows of several of the Hawaiian Islands appears to have decreased during the past 5 m.y. This phenomenon, which has also been observed in rocks from Europe, Iceland, Alaska, Antarctica, the Galapagos Islands, and the western United States, may be caused by a decrease in dipole wobble, a decrease in the nondipole component of the earth's magnetic field, or a combination of these causes. The mean VGP of several lava sequences are displaced to the side of the earth's rotation axis away from Hawaii, which supports the hypothesis that the axial dipole is displaced slightly northward from the earth's

center. Three VGP excursions were recorded in sections of lavas in the Waianae and Koolau Ranges of Oahu. During these excursions the VGP appear to be traveling away from or toward the geographic axis along great circle paths, which suggests that they may represent changes of the dipole rather than the nondipole field and may record aborted reversals in polarity or rapid but infrequent dipole tilts. The studies, reported by R. R. Doell and G. B. Dalrymple, were made on the islands of Oahu, Kauai, Niihau, Nihoa, and Necker.

Ancient latitude of Midway atoll from paleomagnetic measurements

Inclinations of natural remanent magnetism measured by C. S. Grommé in core samples of lava flows underlying the reef limestones of Midway atoll indicate that the volcanic substructure was formed at a latitude of about 15° N. These lavas have been dated by the potassium-argon method at 16 m.y. The present latitude of Midway is 28° N., indicating a northward component of motion of the Pacific crustal plate of about 1,400 km since that time.

Decay of marine magnetic anomalies

Natural oxidation of titanomagnetite to titanomaghemite has been demonstrated by C. M. Marshall in a detailed study of the weathering of submarine pillow lava dredged from near the Juan de Fuca Ridge. Accompanying this progressive oxidation is a reduction in the intensity of natural remanent magnetization although the direction of the magnetization does not change. These results are a further demonstration that the gradual diminution of linear marine magnetic anomalies away from oceanic ridge crests is due to submarine weathering of the magnetized lavas that cause the anomalies.

Paleomagnetism in Iceland

A paleomagnetic study of Icelandic lavas reported by R. R. Doell includes the following: (1) Directions in lavas erupted in 1729, 1783, and 1875 do not support the previously postulated cycloid path for the Icelandic geomagnetic pole, (2) application of geomagnetic reversal stratigraphy shows that the Bering Strait opened more than 3 m.y. ago (which is the date Pacific boreal mollusks first appeared in Icelandic waters) and that there were nine (or more) extensive glaciations in Iceland in the last 2 m.y., and (3) superposed lavas of Snaefellsness contain a record of a pronounced excursion of virtual geomagnetic poles to very low latitudes.

Montana volcanic rock magnetizations

New remanent and induced magnetization data of Upper Cretaceous glassy welded tuffs, volcanic breccias, and hydrothermally altered basalts from western Montana have been interpreted by W. F. Hanna in light of petrographic, thermomagnetic, potassium-argon radiometric, and observed field data. Results indicate that (1) the earth's magnetic field was alternately normal and reversed about 78 m.y. ago, (2) relatively strong remanent magnetization of the glassy tuffs may largely reside in submicroscopic single-domain magnetic constituents within the glass itself, (3) breccias of questionable mudflow or pyroclastic origin were deposited at temperatures of at least 250°C, and (4) altered basalts within a mining district have anomalous or weak total magnetizations relative to neighboring plutonic rocks, a fact explaining the presence of a major negative aeromagnetic anomaly over the mineralized region.

Dating Precambrian rocks by paleomagnetism

Upper Precambrian lava flows and red sandstones of the middle part of the Grand Canyon Series of northern Arizona have been found by D. P. Elston and G. R. Scott to carry a stable remanent magnetization. The paleomagnetic pole positions for these rocks appear to fall in sequence along the polar wandering path for North America that is obtained from radiometrically dated Precambrian rocks. Hence, the Grand Canyon Series rocks can be broadly dated by paleomagnetic techniques, and the indicated age range is roughly 1.0 to 1.2 b.y.

COMPUTER MODELING OF GEOLOGIC PROCESSES

Modeling of earthquake triggering by fluid injection

J. H. Dieterich reports development of plane-strain and three-dimensional finite-element computer models that simulate the static and dynamic deformations of earthquake sequences on an active fault. Values for the static and dynamic friction of the fault are derived from laboratory experiment and are employed as the principal input parameters for the computations. When subjected to a uniform rate of tectonic loading, the model generates a sequence of earthquakes that vary in magnitude and occur at different locations on the fault. Decreases in stress, variations of magnitude with rupture length, and other source parameters for the simulated earthquakes agree with observations for real earthquakes. Earthquakes caused by fluid injection at Rangely, Colo., have been simulated by allowing friction to vary with time and from point-to-point on the fault as a function of changes in fluid pressure. At a constant rate of injection it is found that earthquakes become less frequent with time but increase in magnitude. The magnitude-frequency characteristics of the earthquakes triggered by fluid injection are apparently sensitive to fluid pressure gradients.

Gravity and magnetic interpretation

R. G. Henderson, M. H. Goodman and L. E. Cordell are developing a method for the quantitative interpretation of

magnetic and gravity anomalies in the frequency domain. By a simple normalization procedure on the amplitude spectrum, the effects of uniform magnetization or uniform density contrast are completely eliminated, and intrinsic depth factors which are related only to the geometry of the causal body can be obtained. This procedure allows simple analysis of the anomaly in terms of the parameters of an equivalent prismatic body. With sufficient data the method yields good results and may be used to determine depth and thickness parameters. Additionally, it is possible to ascertain the likelihood that the gravity and magnetic spectra are derived from the same body.

Automatic interpretation of Schlumberger electrical soundings

A. A. R. Zohdy developed a computer program for the automatic interpretation of vertical electrical sounding curves. The code employs field data that has been manually smoothed and digitized and yields a completed interpretation for layer thicknesses and resistivities in less than 10 sec on the IBM 360/65 computer.

GEOCHEMISTRY, MINERALOGY, AND PETROLOGY

EXPERIMENTAL GEOCHEMISTRY

Phase relations of pyroxene

J. S. Huebner, with the help of Malcolm Ross, has constructed a phase diagram illustrating relationships between the solidus for pyroxene crystallization from melts and subsolidus relationships between different pyroxene phases having compositions in the quadrilateral plane $MgSiO_3$-$FeSiO_3$-$Ca_{0.5}Fe_{0.5}SiO_3$-$Ca_{0.5}Mg_{0.5}SiO_3$ in the system CaO-MgO-FeO-SiO_2. The subsolidus region, known from crystallographic and chemical studies with Malcolm Ross and Eric Dowty, consists of two nearly colinear miscibility gaps, augite + orthopyroxene and augite + pigeonite, which are intersected by a third gap between orthopyroxene and pigeonite. The pyroxene phases that will crystallize from a multicomponent melt depend on whether or not, and where, the solidus surface for that composition impinges on these subsolidus miscibility gaps. For example, where crystallization of basaltic melts intersects the gaps between augite and calcium-poor pyroxene, the composition differences between the coexisting pyroxenes are large in terrestrial magmas containing water; in the dry basaltic rocks from the moon, the composition differences are much smaller.

Experimental anatexis

R. L. Tuthill Helz has done melting experiments on rocks of basaltic composition at 5 kb of water pressure (R. L. Tuthill, 1968) and has now completed a study of the melt fraction of the products using the electron microprobe. All partial melts produced at temperatures below the breakdown of hornblende are quartzo-feldspathic in composition with low contents of TiO_2 and FeO and extremely low contents of MgO. On Harker diagrams, variations of Al_2O_3, CaO, Na_2O, and K_2O differ distinctly from their variations in calc-alkalic magmas produced by fractional crystallization with removal of plagioclase. An example of the latter is given by N. L. Bowen (1956) in his discussion of Fenner's Katmai series. A calc-alkalic rock series produced by progressive anatexis of a hydrous basalt of constant composition should resemble the experimental variations and therefore should be distinguishable from fractionation series of Katmai type. This distinction and others between anatexis and fractional crystallization place important chemical constraints on tectonic models of magma generation using oceanic crust as starting material.

Viscosity of magmatic silicate liquids

H. R. Shaw developed an empirical method to predict viscosities of multicomponent silicate liquids. Five numerical coefficients permit calculation of viscosities as a function of temperature for either anhydrous or hydrous compositions. The results reproduce existing experimental measurements with uncertainties usually less than a factor of two for viscosities ranging from about 1 to 10^8 poises and compositions ranging from lunar basalt to hydrous granite. Existing data also suggest that the method may be valid for anhydrous rhyolite compositions at viscosities as high as 10^{13} poises under conditions of internal equilibrium (specimens perfectly annealed at the temperature of measurement). These results simplify and extend the viscosity correlations of Yan Bottinga and D. F. Weill (1972). Availability of accurate predictive schemes will permit significant numerical advances in the understanding of transport properties of magma and their role in igneous differentiation.

Thermochemical data

E-an Zen has evaluated thermochemical parameters derived from many different experimental studies of hydrothermal phase equilibria involving aluminous phases. The data show conclusively that the standard-state enthalpy value for corundum is in serious error. This error means that calculations on many important metamorphic reactions are highly uncertain. New determinations of the enthalpy of formation of corundum are urgently needed.

P. B. Hostetler and C. L. Christ (1971) have used thermochemical data to calculate the stable and metastable relations among some important minerals in the system MgO-CaO-SiO_2-CO_2-H_2O at 25°C and 1 atm. In the absence of calcium, talc is stable relative to chrysotile + quartz and sepiolite is metastable relative to talc, even in the presence of amorphous silica (120 ppm SiO_2 in solution). According to calculation, talc and tremolite should be common products of geological reactions

in aqueous environments at low temperatures. Their scarcity in such environments probably reflects difficulty in stripping H_2O molecules from hydrated magnesium ions in solution. The occurrence of authigenic talc in evaporite deposits supports this interpretation.

P. B. Hostetler (USGS), J. J. Hemley (Anaconda Co.), C. L. Christ (USGS), and J. W. Montoya (Anaconda Co.) (1971) have experimentally determined the equilibrium between talc and chrysotile in solutions containing silicic acid at 90°C, 1 atm, and also at 200° to 450°C, 1,000 atm. The two sets of data are mutually consistent, and the results show that the equilibrium curve lies below the quartz solubility curve at all temperatures of the study. That is, talc is stable relative to chrysotile + quartz under these conditions. The free energy of formation of talc (25°C) calculated from the experimental data using tabulated free energy data for chrysotile, water, and H_4SiO_4 is several kilocalories less negative than the value given by R. A. Robie and D. R. Waldbaum (1968). The value calculated from the experiments is supported by the observation that the published value predicts equilibrium concentrations of SiO_2 in solution that are too low to be geologically reasonable.

P. B. Barton, Jr., used data on ratios of H_2S to H_2 in equilibrium with high digenite ($Cu_{2-x}S$) as published by Hans Rau (1967) to calculate activities of Cu_2S in digenite as functions of temperature and composition. The solid solution is found to be highly nonideal, a feature common to other solid solutions of defect type. The results greatly augment thermodynamic data for phases in the copper-sulfur system and are important to the understanding of other reactions in ore deposits containing copper sulfides.

MINERALOGIC STUDIES IN CRYSTAL CHEMISTRY

CRYSTAL CHEMISTRY OF THE SILICATES

Titanian fassaite from the Allende meteorite

A crystal structure refinement and optical study have been completed by Eric Dowty and J. R. Clark on a titanium-rich pyroxene, a titanian fassaite from the Allende meteorite with a composition $Ca_{1.00}Mg_{0.39}Ti_{0.48}Al_{0.13}(Si_{1.27}Al_{0.73})O_6$. Most of the titanium within the crystal structure is found to be trivalent and occurs in the octahedral $M1$ sites rather than the tetrahedral sites. A strong band at 16,500 cm^{-1} in the optical spectrum for light vibrating in (100) probably represents charge transfer between Ti^{+3} and Ti^{+4} in the octahedrally coordinated ($M1$) cation site of the structure. Pronounced differences between the color, pleochroism, and optical spectra of the Allende pyroxene and those of terrestrial titanian pyroxenes suggest that Ti^{+3} is essentially absent from the latter. The Allende meteorite formed in an extremely reducing environment in which Ti^{+3} and iron metal are stable species.

Intragranular variation in hornblende composition, Finnmarka Complex, Norway

Electron-microprobe and partial wet-chemical analyses by G. K. Czamanske and D. R. Wones of selected homogeneous areas within amphibole grains in granodiorite from Finnmarka Complex, Norway, show marked chemical variations although single crystal X-ray photographs do not reveal multiple phases. Associated minerals are plagioclase, perthite, biotite, magnetite, ilmenite, sphene, and quartz. The following three analyses show the range and trends of amphibole compositions at the indicated sites:

A	*M4*
$K_{0.13}Na_{0.37}$	$Ca_{1.72}Mn_{0.16}Na_{0.12}$
$K_{0.06}Na_{0.15}$	$Ca_{1.68}Mn_{0.17}Na_{0.15}$
$K_{0.01}Na_{0.03}$	$Ca_{1.91}Mn_{0.08}Na_{0.02}$

M1–M3

$Mg_{3.29}Fe^{2+}_{1.29}Fe^{3+}_{0.23}Mn_{0.01}Al_{0.04}Ti_{0.15}$
$Mg_{3.49}Fe^{2+}_{1.16}Fe^{3+}_{0.21}Mn_{0.04}Al_{0.06}Ti_{0.04}$
$Mg_{3.52}Fe^{2+}_{1.13}Fe^{3+}_{0.20}Mn_{0.15}$

T

$Si_{7.07}Al_{0.94}$
$Si_{7.51}Al_{0.49}$
$Si_{7.83}Al_{0.16}$

Because all analyses involve a single rock unit, a detailed scheme of multiple coupled substitutions can be developed. As the amphibole responded to progressively more oxidizing magmatic conditions, Fe:(Fe+Mg) decreased from 0.32 to 0.27, while titanium in the amphibole became less stable and decreased markedly as did aluminum, sodium, and potassium. This behavior is analogous to experimental data in which the stability of iron-rich amphiboles is enhanced by aluminum substitutions which provide a better fit between the tetrahedral and octahedral strips within the crystal structure.

One atmosphere augite-pigeonite solvus and orthopyroxene-pigeonite reaction loop

Malcolm Ross, J. S. Huebner, and Eric Dowty have carried out stepwise heating with controlled oxygen fugacity of lunar augite and pigeonite single crystals having exsolved pigeonite and augite, respectively. These experiments have permitted delineation of an augite-pigeonite solvus by using results of optical examinations and precession X-ray photography of crystals quenched between heating steps. Temperatures of homogenization and of first melting are generally indistinguishable; thus, the temperatures of crystallization can be defined for the following coexisting augite-pigeonite pairs (host and exsolved phase, respectively; mole percent): 1176°C, $Wo_{14}En_{58}Fs_{28}$–$Wo_{34}En_{46}Fs_{20}$; 1150°, $Wo_{33}En_{45}Fs_{22}$–

$Wo_{12}En_{58}Fs_{30}$; 1025°, $Wo_{27}En_{23}Fs_{50}$–$Wo_{15}En_{28}Fs_{57}$; 970°, $Wo_{25}En_{16}Fs_{59}$–$Wo_{14}En_{18}Fs_{68}$; and 960°, $Wo_{24}En_{11}Fs_{65}$–$Wo_{14}En_{16}Fs_{70}$. The compositional trends of the augite and pigeonite are approximately parallel to the En-Fs join. Immediately above the homogenization temperature, augite reacts to form calcium-rich augite (Wo_{45-50}) + liquid, whereas, depending on the initial Wo content, pigeonite reacts to form either pigeonite + augite + liquid or orthopyroxene + augite + liquid. Terrestrial orthopyroxenes of En content 87 to 14 (Wo≤3) were similarly heated to determine the maximum possible temperatures for the phase boundary between the Opx and the Opx + pigeonite fields. A fairly smooth temperature-composition curve is described: En_{87} (1260°C), En_{86} (1245°), En_{80} (1210°), En_{77} (1205°), En_{75} (1195°), En_{61} (1120°), En_{42} (1035°), En_{30} (975°), En_{21} (955°), En_{14} (955°). Partial melting accompanies the reaction to form pigeonite from orthopyroxenes more En-rich than En_{61}. This intersection of the solidus and the Opx-pigeonite reaction loop explains the commonly inferred transitions from orthopyroxene to pigeonite in the crystallization of basic magmas (Ross and others, 1971).

Relationship of the two dimorphous vanadium silicates, cavansite and pentagonite

The new mineral from Oregon, cavansite, $Ca(VO)(Si_4O_{10})\cdot 4H_2O$, had been shown (L. W. Staples and others, 1972) by crystal-structure study to be a novel layer silicate with zeolitic character. Its dimorphous companion has now been fully studied by H. T. Evans, Jr., and found also to be a layer silicate but with an entirely different type of tetrahedral linkage in the layer. The striking fivefold twin behavior of pentagonite is fully accounted for in terms of its structure. The zeolitic behavior of cavansite has been followed with a heating, powder X-ray diffraction technique (Guinier-Lenne), which shows that the unit cell volume shrinks continuously and reversibly up to about 380°C where the mineral decomposes and becomes glassy. Two sharp reversible transitions appear at 240° and 310°C (±10°). The optical and physical properties of both minerals have been determined.

BORATE FRAMEWORK OF BORACITE AND ITS RELATIONSHIP TO THE FERROELECTRIC EFFECTS

New crystal-structure refinements by Eric Dowty and J. R. Clark (1972) of orthorhombic boracite, $Mg_3ClB_7O_{13}$, and of its trigonal iron-rich isomorph, $Fe_{2.4}Mg_{0.6}ClB_7O_{13}$, show that some boron and oxygen atoms, as well as the metal and halogen atoms, are involved in producing the ferroelectric effects. The borate framework is composed of linked tetrahedra and triangles; there are no borate pyramids as described for the cubic structure (T. Ito and others, 1951). The atomic displacements associated with ferroelectric polarity changes are as large as 0.6 A.

NEW DATA ON COLLINSITE AND DYPINGITE

Chemical and X-ray powder diffraction studies by M. E. Mrose have demonstrated that a milky-white translucent mineral found in sheaf-like aggregates on specimens collected at the Tip Top mine, Custer County, S. Dak., is collinsite, a member of the triclinic fairfieldite group of minerals. A chemical analysis by Amos Lingard and Willard Roberts of the South Dakota School of Mines shows that this is an iron-free collinsite which has a composition of $Ca_{2.00}(Mg,Zn)_{0.98}(PO_4)_{2.00}\cdot 2.02H_2O$, with Mg:Zn=0.97:0.03, and is very close to the empirical formula $Ca_2Mg(PO_4)\cdot 2H_2O$. The Tip Top collinsite which occurs in the center of completely altered triphylite nodules is intimately associated with xanthoxenite, leucophosphite, colorless apatite, brown fibrous rockbridgeite-frondelite, and todorokite. The South Dakota locality, the third known locality for collinsite, is the first reported for the United States.

An unidentified phase (admixed with nesquehonite, $MgCO_3\cdot 3H_2O$) synthesized by B. S. Hemingway in the system MgO–CO_2–H_2O has been identified by M. E. Mrose as the synthetic equivalent of dypingite, $Mg_5(CO_3)_4(OH)_2\cdot 5H_2O$, recently described from a serpentine-magnesite deposit at Snarum, Norway. The pure phase has been synthesized in the temperature range 45° to 60°C, using as starting materials equal volumes of 1*M* $MgCl_2\cdot 6H_2O$ and 1*M* Na_2CO_3.

NEW PROCEDURES FOR MINERAL ANALYSIS

A simple device has been designed by H. T. Evans, Jr., and utilized by R. P. Christian (1972) to allow chemical analysis of the small (≈0.1 mm) single crystals used for crystal structure studies. The device supports and positions the crystal, mounted on a glass fiber held in a brass spindle for the diffraction instruments, in the X-ray milliprobe apparatus normally used for flat samples. Thus, a crystal under structural study can be placed in the X-ray fluorescence apparatus and then returned to the diffraction equipment without disturbing the crystal itself. This technique is of importance in the frequent situation where the structural interpretation requires knowledge of the composition of the crystal grain actually studied, rather than that of the bulk sample from which it was selected.

Electron microprobe studies by G. A. Desborough show that natural alloys from Goodnews Bay, Alaska, composed principally of platinum and iron may contain significant amounts of Ir, Os, Rh, Ru, and Pd, all occurring in both solid solution and as separate alloys. The alloy composed principally of platinum and iron may be accurately analyzed for all the above elements with the electron microprobe using no empirical corrections when appropriate standards are employed.

Two new X-ray powder cameras have been placed in use by H. T. Evans, Jr. One of these is the Guinier-Hagg camera, a focusing instrument, which provides pattern of high quality and resolution using strictly monochromatized radiation,

either Cu$K\alpha_1$ or Cr$K\alpha_1$ ($K\alpha_2$ is completely eliminated). This method, which requires less than 10 mg of sample, gives results equal to or better than those given by the powder diffractometer.

The second instrument is the Guinier-Lenne camera, which is also a focusing instrument. It is equipped with a vacuum furnace to heat the sample over a range of 20° to 1,200°C and a moving film to record the pattern continuously while the sample is heated or cooled. Thus, on a single film the thermal expansion and the transitions that occur over a wide temperature range can be identified and measured. The instrument has now been placed in effective operation and tested on a number of samples: $CaCO_3$, $NaNO_3$, quartz, chalcocite, hydromagnesite, nesquehonite, and cavansite.

For chalcocite, the phase changes from low to high chalcocite (150°C) and from high chalcocite to high digenite (≈300°C) are clearly shown. For hydromagnesite two changes are apparent, one at ≈275°C and a second (to periclase) at ≈320°C. Nesquehonite is much less stable and decomposes at 70°C to an amorphous state; periclase appears at ≈370°C. In cavansite the zeolite loss and recovery of water is shown by a shrinkage of the unit cell which is discontinuous but reversible at two points (240° and 310°C). In such experiments the powder lines can be measured with considerable accuracy at a series of temperatures, unit cells can be refined, and parameters can be plotted at any desired intervals over the whole temperature range, all from one film. Such plots show most clearly the thermal expansion (or contraction), the physical and chemical phase changes, and the onset of disorder and so forth for the substances under investigation.

VOLCANIC ROCKS AND PROCESSES

Origin of Hawaiian Ridge—Emperor Seamount chain

The Hawaiian Ridge and Emperor Seamounts appear to form a single chain of tholeiitic shield volcanoes that erupted sequentially on the floor of the central Pacific Ocean during Tertiary and Quaternary time. The chain cuts obliquely across the older Cretaceous structural patterns of that sea floor. While the pattern of the chain as a whole is linear, E. D. Jackson, E. A. Silver, and G. B. Dalrymple (1972) have shown that the individual volcanoes lie on short sigmoidal en echelon loci that are subparallel with respect to each other and that may represent extensional features in the crust and upper mantle. In general, the order of eruption progressed from northwest to southeast along the chain, but potassium-argon dating shows that the rate of progression of volcanism along individual loci is nonlinear where best studied in the southeastern part of the chain. Furthermore, simultaneous eruptions appear to have occurred within a distance along the chain of about 200 to 400 km. The available data are consistent with the Wilson-Morgan hypothesis that relates their genesis to the motion of the Pacific crust over a melting spot in the mantle. This melting spot, which may be due to either excess heat or pressure release, appears to have a diameter of about 300 km and is presently centered slightly north of the island of Hawaii. Paleomagnetic inclinations found by C. S. Gromme (1972) in Midway basalts suggest that Midway Island formed at a latitude similar to that of the island of Hawaii and, therefore, that the melting spot may be fixed with respect to the geographic axis. The bend in the Hawaiian-Emperor chain probably reflects a significant change in the motion of the Pacific plate. The best estimate of the age of the Hawaiian-Emperor bend, based on the existing radiometric data, is 24.6±2.5 m.y., which correlates with a time of increased tectonic activity in the western Pacific island arcs and along the northern and eastern boundaries of the Pacific plate. The vector change in the motion of the Pacific plate with respect to the melting spot that is required to produce the bend is about 12 cm/yr in a west-southwestward direction.

Theory of melting for the Hawaiian Ridge

H. R. Shaw has developed a dynamic theory for the magmatic evolution of the Hawaiian Ridge that is consistent with the kinematic descriptions by Ian McDougall (1964, 1971) and E. D. Jackson and others (1972). It is based on the concept of thermal feedback as applied to magma generation by H. R. Shaw (1969). The geological data interpreted by this model give derived values of dynamic variables for the asthenosphere that are similar to the earlier estimates by Shaw (1969) based on entirely different data (an average shear stress of about 100 bars and an average effective viscosity of 10^{21} poises). Shaw's general conclusions are that velocity gradients of mantle flow act as melting guides for the oceanic island chains. These chains reflect maxima of viscous heating in the asthenosphere acting in conjection with preexisting temperature and melting point gradients. The melting spot of Jackson and others (1972) resembles a wave front localized by lower average temperatures of the asthenosphere in the direction of lithosphere foundering and by higher melting temperatures ahead of the ridge front caused by volcanic depletion of fusible components. Evidence suggesting that such melting spots are fixed relative to the deep mantle does not require that the magma source arise there from a vertical convective plume.

Age and paleomagnetism of Hawaiian rocks

R. R. Doell and G. B. Dalrymple have completed paleomagnetic and potassium-argon measurements on 786 oriented cores from 99 volcanic units at 18 sites in the Waianae and Koolau ranges, Oahu. The data show that the subaerial Waianae volcano was active only from about 3.6 to 2.4 m.y. ago and the subaerial Koolau volcano from about 2.6 to 1.8 m.y. ago. There is some evidence that Waianae volcano was still active when Koolau Volcano emerged from the sea. The predominantly thoeliitic lower and middle members of the Waianae Volcanic Series are approximately contemporaneous

and were extruded during the late Gilbert and early Gauss geomagnetic polarity epochs. They were followed within 200,000 yr by the alkalic lavas of the upper member, which was probably extruded largely during the latter part of the Gauss normal polarity epoch. The Koolau Volcanic Series was extruded entirely during the early Matuyama reversed epoch. Data from three thick stratigraphic sections in the Waianae and Koolau Volcanic Series indicate that accumulations of lava flows as much as 470 m thick can be extruded in less than 250,000 yr and that the maximum average period between superimposed lavas is on the order of 1000 yr.

Eruptive activity, Kilauea Volcano, Hawaii

The longest rift eruption in Kilauea's recorded history lasted from May 1969 to October 1971. After 4 months of quiescence, a new eruption began and is continuing at this writing. These eruptions have provided a unique opportunity for D. W. Peterson and staff of the Hawaiian Volcano Observatory to study the growth and development of a new volcanic shield (D. A. Swanson and others, 1971). Early months of the eruption included episodes of high fountaining, but these ended in December 1969. During the first half of 1970, the eruptive activity included many lava overflows and a rising and falling lava column that fluctuated in response to degassing cycles. Aloi Crater was completely filled in April, and by June a distinct shield-shaped structure had grown to a height of about 100 m and a diameter of 1 km; it was formally named "Mauna Ulu" ("Growing Mountain" in Hawaiian). In July eruptive activity shifted to vents centered along an east-northeast extension of Mauna Ulu's main fissure while a lava lake, whose level continually fluctuated, occupied the summit crater. Continuously erupting lava flowed mostly southward, and a complex system of lava tubes developed. Tubes from Mauna Ulu fed into the north side of a crusted-over lava reservoir that occupied Alae Crater, and exit tubes drained lava from Alae toward the south. Pahoehoe lava, fed from tubes, entered the ocean near Kahue Point for a week in September.

In October and November, a row of small pit craters developed on Mauna Ulu's east flank, and in December they merged to form a long trench. The trench and Mauna Ulu's summit crater enlarged by progressive collapse of walls, and in April 1971 they coalesced to form a single depression about 650 m long. From February to May, great surges of lava flowed southward both in tubes and on the surface, and for about 2½ months pahoehoe entered the ocean, adding almost 500,000 m^2 of new land to the island. In mid-May, the lava lake in Mauna Ulu's summit crater began to subside; in mid-June the rate of flow in the lava tubes began to decline, and by September flow had stopped. The lake was completely drained by mid-October, thus ending the first Mauna Ulu eruption which in 875 days had produced about 185×10^6 m^3 of lava that covered about 50 km^2 of land.

As the Mauna Ulu eruption waned, Kilauea's summit region began to inflate rapidly in June 1971. On August 14 lava fountains burst from fissures in the southern part of Kilauea caldera and lasted for about 10 hr. This eruption produced only minor deflation and was followed by continued tumescence leading to another eruption, which lasted from September 24 to 29 and included activity in Halemaumau, Kilauea caldera, and Kilauea's southwest rift. The September eruption was dramatic and locally destructive; the floor of Halemaumau subsided 45 m in a single day, two seismometers were destroyed, and an observatory vault was inundated.

The September eruption, which caused little deflation, was again followed by rapid tumescence that continued until early February 1972, when a new eruption began at Mauna Ulu. The onset of the eruption ended the tumescence, and the continuing eruption is accompanied by only minimal deflation of Kilauea's summit. The complex relations between the volcanic activity of Kilauea and ground deformation, seismicity, and other physical and chemical parameters will continue to be studied closely by members of the Hawaiian Volcano Observatory.

Seaward displacement of Kilauea's south flank

Repeated geodetic measurements of Kilauea's south flank are revealing a systematic pattern of deformation that correlates with both seismic and eruptive activity. By comparison of recent data with earlier measurements, D. A. Swanson, W. A. Duffield, and R. T. Okamura (1971a, b) have found that certain parts of the south flank have moved seaward as much as 4.5 m and upward as much as 2 m. The rate and magnitude of displacement can be related both in space and time to eruptions along the east rift zone, suggesting that magma forcibly injected into Kilauea's east rift could be causing the observed displacement.

Depletion of volatiles during lava flow

B. P. Fabbi and D. A. Swanson have found from analysis of fresh lava samples from Kilauea Volcano that total sulfur content is systematically depleted during flowage of pahoehoe lava. The sulfur content of dipped melt samples taken at the Mauna Ulu vent is about 140 ppm but decreases in a linear fashion to about 55 ppm for samples collected 12 km from the vent. These data yield a rate of sulfur loss of about 7 ppm per hour of lava flowage. Glassy skins on cooled flows are depleted in sulfur by about 20 to 30 ppm relative to the melt at comparable distances from the vent, an observation suggesting that sulfur is lost during the natural cooling process.

Chemically bound water (H_2O+) also is lost during the degassing-while-flowing process; samples taken at the vent have about 440 ppm H_2O+, but those taken at 12 km distance have only 230 ppm H_2O+. Chlorine and fluorine likewise are lost but in very small amounts. Analyses indicate that Mauna Ulu lavas, during periods of high fountaining, contain more water

than lavas between those periods or after the last high fountains in December 1969. Furthermore, there is a clear inverse correlation between water content of fountain pumice and the height of the fountain. Low fountains (less than 100 m high) produced pumice with total water content of about 700 ppm, whereas fountains higher than 400 m produced pumice with a total water content of 300 ppm or less. This relation suggests that the pumice loses water rapidly during the fountaining; the higher the fountain, the longer the pumice remained hot enough to lose water. These findings indicate that, to study initial volatile contents of basaltic lava, it is necessary either to dip melt directly from the vent or to use only those pumice and spatter samples produced by low fountains.

Electromagnetic studies at Kilauea Volcano

Electromagnetic studies in the summit region of Kilauea Volcano by G. V. Keller (Colorado School of Mines) and D. B. Jackson (USGS) revealed a distinct conductivity anomaly centered about 1 km south of Halemaumau and estimated to be about 1 km deep. The location of the anomaly coincides with the center of deformation of the volcano during the summer and fall of 1971. The authors interpret the cause of the anomaly as a rising hot-water convection cell.

During the course of their work, on July 22, 1971, they encountered large background noise voltages at a site near Keanakakoi Crater (Keller and others, 1972). The noise was so troublesome that efforts to obtain a record from this site had to be abandoned; no other sites gave similar trouble. On August 14, lava erupted from vents close to the Keanakakoi recording site. Thus the high background noise level may possibly be associated with the impending eruption, but further studies are required to assess the feasibility of using electromagnetic data as a predictive tool.

Wrangell volcanic field, Alaska

Reconnaissance surveys of the unmapped northern part of the Wrangell volcanic pile in south-central Alaska by D. H. Richter and R. L. Smith and local detailed studies by P. C. Lowe (Univ. Colorado) have revealed a greater complexity of Quaternary-Tertiary volcanic activity than heretofore realized. Many previously unrecognized eruptive centers were mapped including 9,000-ft Mount Gordon, a Pliocene-Pleistocene, andesite volcano.

Along the northern perimeter of the Wrangell field a series of basalt flows (45 percent SiO_2), as much as 300 ft thick, constitute the earliest eruptive products. These basalts are overlain by a complex of rhyodacite-rhyolite flows and domes (72–74 percent SiO_2) and silicic ash-flow and ashfall deposits locally interbedded with lahars and Tertiary glacial deposits. Basaltic andesite and andesite flows (51–60 percent SiO_2), interbedded with andesite lapilli tuff, appear toward the top of the rhyolite succession. South toward the high crest of the Wrangell pile, silicic effusives are not evident. The bulk of the rocks are basaltic andesite, andesite, and dacite flows (51–64 percent SiO_2) with occasional thick blankets of dacite lapilli tuff erupted from a number of volcanic centers.

The apparent increase in potassium content from south to north across the pile and recent theories concerning plate motion in the north Pacific suggest that Wrangell volcanism was the result of strong northward underflow of Pacific oceanic crust and mantle commencing sometime during the Miocene. Underthrusting probably ceased in the Pliocene apparently due to a change in direction of plate motion. Vigorous volcanic activity probably waned at this time, but local volcanism persisted through the Holocene.

Eruptive products of Mount St. Helens

Mount St. Helens volcano in the Cascade Range in southern Washington has erupted pumice or scoria more than 50 times between about 35,000 and 170 yr ago. The resulting tephra layers have been divided by D. R. Mullineaux into eight groups, each containing a characteristic ferromagnesian mineral suite that distinguishes it from the group above and below it. Tephra deposits of the six most voluminous and widespread groups are extensive in and east of the Cascade Range and should prove to be important time-marker beds in late Pleistocene and Holocene deposits of northwestern United States and southwestern Canada.

A complex assemblage of fragmental volcanic deposits that fills a valley southeast of Mount St. Helens records at least two prolonged episodes of explosive dacitic volcanism. According to D. R. Crandell the valley fill, which is 1 to 2 miles wide and locally 300 ft thick, is found from the base of the volcano downvalley for an overall distance of 50 mi. Deposits of hot pyroclastic flows predominate in the first 10 mi of the fill, lahars are present as far as 35 mi from the volcano, and the part of the fill that is farthest downvalley consists of fluvial deposits. Radiocarbon dates on wood in the fill deposits indicate that the initial eruptive episode occurred about 12,000 yr ago and the second episode, between 2,900 and 2,500 yr ago.

Chemical classification of Columbia River basalts

Lavas of the Columbia River Group have been classified by T. L. Wright, M. J. Grolier, and D. A. Swanson into 15 magma types comprising at least three chemical series. A four-unit informal stratigraphic subdivision is used to correlate chemical composition with stratigraphic position. The relation between chemistry and stratigraphy from upper to lower is summarized as follows:

upper Yakima Basalt: Diverse compositions include one flow with exceptionally high "FeO" (17.7 percent) and P_2O_5 (1.6 percent).

middle Yakima Basalt (Late Yakima-type of A. C. Waters, 1961): Flows have relatively low MgO (2.5–5.5 percent),

high TiO_2 (2.7–3.2 percent), and low SiO_2 (49.0–54.5 percent).

lower Yakima Basalt: Flows have relatively low MgO (3.0–5.5 percent), low TiO_2 (1.5–2.1 percent), and high SiO_2 (53.0–56.5 percent).

Picture Gorge Basalt and lower basalt: Flows have relatively low MgO (4.7–7.2 percent), low TiO_2 (1.4–1.9 percent), and intermediate SiO_2 (49.5–52.0 percent).

Within each chemical-stratigraphic subdivision the flows in the eastern part of the Columbia Plateau are commonly richer in TiO_2 than equivalent flows in the western part.

Sources for the youngest flows of the upper Yakima Basalt are near Pasco, Wash. (Swanson and others, 1972). Sources for the Picture Gorge and lower basalt are partly known from previous work. Other sources are yet to be adequately defined chemically.

G. W. Walker, in a reconnaissance of Columbia River basalts in Union and Wallowa Counties of northeast Oregon, has delineated a widespread key sedimentary horizon that separates an underlying thick sequence of flows and flow breccias, principally of Yakima-type chemistry, from an overlying unit of flows of mixed chemistry. The upper unit of flows, which represent a stratigraphically restricted part of the Columbia River basalt, is of late Miocene or Pliocene age. Chemical analyses of flows from this upper unit indicate the first reported occurrence of Late Yakima-type basalt in the region and the close stratigraphic association of Yakima-type and Late Yakima-type flows, as well as andesite. The andesite is the most silicic flow rock yet found on the Columbia Plateau.

Volcanic complex of the Ritter Range pendant

Continued field mapping by R. S. Fiske and O. T. Tobisch in the Ritter Range pendant, Sierra Nevada, Calif., disclosed complex contact relations between the 1- to 2-km-thick deposit of massive pyroclastic slump breccia that underlies the central and western parts of the Ritter Range and the thick deposit of ash-flow tuff that underlies the eastern part of the range. Near the western end of Thousand Island and Garnet Lakes, the ash-flow tuff appears to grade upward into the heterolithologic slump breccia, although west of Lake Ediza a thick section of welded ash-flow tuff abuts sharply against the breccia. It has tentatively been interpreted that the massive slump breccia was deposited on top of the ash-flow tuff soon after it was erupted. The lower parts of the breccia mixed with the nonwelded top of the ash flow forming the hybrid contact rocks exposed near Thousand Island and Garnet Lakes. Elsewhere, as near Lake Ediza, complex slumping presumably removed large parts of the upper, nonwelded part of the ash flow, and the slump breccia rests directly upon and against welded tuff. The great thickness of the ash-flow deposit (locally as much as 400 m), is compatible with the interpretation that the ash flow ponded in a caldera. The pyroclastic slump breccia that is so intimately associated with the ash-flow tuff may therefore have been the result of inward slumping from the caldera walls as the floor of the caldera subsided.

Eruption sequence in the northern Jemez Mountains

R. A. Bailey, in a continuing study of the geology and petrology of the Jemez Mountains, New Mex. (R. L. Smith, R. A. Bailey and C. S. Ross, 1970), has subdivided rocks of the Polvadera Group in the Abiquiu quadrangle into the following eruptive episodes: (1) Commencing about 7 m.y. ago, eruption of plateau-forming tholeiitic and alkalic basalts of which the latter have differentiated locally to latite or trachyte, (2) from about 6 to 4 m.y. ago, eruption of large volumes of rhyodacite succeeded by lesser volumes of dacite, andesite, and basalt, and (3) from about 4 to 2 m.y. ago, eruption of rhyodacite and rhyolite, mainly from centers located on a 4-mi-diameter ring fracture concentric on Polvadera Peak, a major older rhyodacite-dacite center.

Polvadera Group rocks are the precursors of the voluminous rhyolites (Tewa Group) associated with the Toledo and Valles calderas, and an understanding of their evolution is important to an understanding of the origin of the Bandelier Tuff magmas (Smith and Bailey, 1966).

Development of pillows in submarine lavas, Mount Etna, Sicily

J. G. Moore, Renato Cristofolini, and Antonino Lo Giudice (1971) report that 11 scuba dives to the submarine extension of recent basalt lava flows erupted on the slopes of Mount Etna reveal that surface features of the submarine part of the flows depend on the steepness of the bottom. Where the slope is gentle, the flow surface is hummocky but relatively smooth and has elongate ridges and tumuli; where it is steep or cliffed, cylinderlike pillows, elongate downslope, drape the scarp and commonly bifurcate into smaller cylindrical or hemispherical pillows. The flows apparently propagate down the submarine slope by frontal development of pillows which, by damming the flow, cause it to thicken and eventually to establish a steep front. Pillows, fed through master channels near the top of the flow, digitate and drape over the steep front of the advancing flow, thus forming a steeply inclined stack of foreset-bedded pillows. Because of these steep initial dips, indications of top and of thickness of ancient pillowed piles should be used with caution. Two features of Etnan flows may prove valuable in determining flow directions in ancient uplifted pillows: (1) Blunt downslope termination of elongate pillows, and (2) division of elongate pillows into two or more smaller pillows in the downflow direction.

Sulfide spherules in vesicles of dredged pillow basalt

J. G. Moore and Lewis Calk (1971) report that virtually all samples of fresh submarine pillow basalt dredged from the ocean floor contain spotted vesicles in their outer glassy margins. The spots also occur in vesicles in some drastically quenched subaerial lavas. The spots are minute spherules,

ranging from 0.2 to 2.5 microns in diameter, that are rather evenly spaced 1 to 8 microns apart on the vesicle walls. Electron microprobe analyses indicate that the spherules are composed primarily of iron, sulfur, copper, and nickel.

The spherules apparently form by diffusion of iron, copper, and nickel from the basalt melt toward preexisting vesicles. The vesicles themselves were probably formed by exsolution of a volatile phase deficient in water and composed primarily of sulfur and carbon compounds; in pillows of average water content, water is too soluble in basalt melt to exsolve at depths greater than a few thousand meters. Reaction of sulfur with iron, copper, and nickel presumably produced droplets of an immiscible sulfide liquid that quenched upon continued cooling and formed the spherules on the vesicle walls.

A similar mechanism may account for the formation of larger, chemically similar sulfide globules (up to 0.5 mm in diameter) that have been found in fresh basalt pillows as well as in surface lava flows. They may form at a melt-volatile interface within a subsurface magma reservoir and then be reincorporated into the melt prior to eruption on the surface.

Gases in recent submarine lavas

Motoaki Sato and J. G. Moore have initiated a systematic mass spectrometer study of gases dissolved in submarine lavas. Because of the problems of fractional degassing of volatiles, which vary with degree of crystallization and total pressure, and of contamination by air and meteoric water, deep sea lavas seem the most suitable for study. Being quenched very rapidly under pressure, they probably contain the least contaminated and fractionated gases. Preliminary data on a dense glassy crust of tholeiitic pillow lava dredged from a depth of 4,680 m on the submarine extension of the east rift zone, Kilauea Volcano, Hawaii, show a total gas content of 5.25 cm^3/g of lava and a volumetric composition (in percent) of 74.88 H_2O, 8.68 N_2, 5.97 H_2, 3.96 SO_2, 2.71 CO_2, 2.55 CO, 0.65 H_2S, 0.33 CH_4, and 0.27 Ar. Measurements are being continued on samples at different depths in order to determine the sequence of fractional degassing with pressure change.

Glass inclusions in olivine crystals

Olivine crystals in the first (Apollo 11) lunar samples and all subsequent lunar samples contain very unusual silicate melt inclusions (Edwin Roedder and P. W. Weiblen, 1970). Tiny samples of the liquid melt, trapped in the crystals during their growth, are common in the minerals of terrestrial lavas. Commonly these melt inclusions have crystallized to form daughter minerals during subsequent cooling. The lunar melt inclusions, however, have crystallized in an odd fashion, each with flat plates of ilmenite and plagioclase oriented parallel with a single crystallographic plane of the enclosing olivine crystal. This phenomenon (internal epitaxy) had never been described before.

Subsequent study has shown, however, that such inclusions are common in lavas from Hawaii and have been missed by previous petrographers (Roedder and Weiblen, 1971). Laboratory heating experiments have been performed on some of these Hawaiian inclusions in an attempt to obtain information on terrestrial (and lunar) cooling rates for these lavas. These experiments show that such oriented daughter crystals can be made to grow in the laboratory only by slow cooling, for example, from 1,100°C to 1,000°C in 6 or more days. Such data are useful in determining flow thicknesses in both lunar and terrestrial basalts (Roedder, 1971c).

Distribution of gold in calc-alkaline rocks

David Gottfried, J. J. Rowe, and R. I. Tilling (1972) have analyzed the gold content of about 700 igneous rocks from many petrographic provinces representing different magma types and widely different geographic areas. The analyses were made by neutron activation techniques that permit detection of as little as 0.2 ppb of gold.

Rhyolites are remarkably uniform and low in gold regardless of provenance and chemical composition. Basalts are variable in gold content, and regional differences may exist within and between basalt provinces. A trend of progressive depletion of gold from mafic to felsic rocks is indicated in calc-alkaline suites.

Similarly, in batholitic suites, gold is lower in felsic members than in related mafic members. The data also indicate that relatively high gold concentrations are associated with earlier crystallizing phases, for example, magnetite and mafic silicates. Gold mineralization associated with granitic rocks having less than 2 ppb gold suggests that such mineralization is not related in any simple way to final crystallization stages of the magma.

PLUTONIC ROCKS AND MAGMATIC PROCESSES

Classification of igneous rocks by late magmatic history

Descriptive and genetic classifications of peridotite-gabbro complexes (Jackson and Thayer, 1972; Thayer, 1971) have led T. P. Thayer and E. D. Jackson (p. B79–B84) to propose a classification of all igneous rocks based on their history of crystallization and emplacement. Rocks that crystallized in place from fluid magma are classed as authigenic; rocks that crystallized completely at one site and moved to another by solid flow are classed as allogenic, and rocks that crystallized at various times and places during emplacement of magmatic mush are polygenic. The classification provides a new basis for comprehending the complete gradational series from authigenic to allogenic rocks as exemplified by cumulate stratiform complexes, porphyritic rocks, and alpine peridotite-gabbro complexes. Few large complexes consist of only one type of rock. Authigenic and polygenic types occur over the complete composition range of igneous rocks, but allogenic rocks seem

to be limited to ultramafic, gabbroic, and possibly anorthositic compositions.

Generation of granitic magmas in the Sierra Nevada batholith

D. C. Presnall and P. C. Bateman have used the experimental data from the system $NaAlSi_3O_8$-$CaAlSi_2O_8$-$KAlSi_3O_8$-SiO_2-H_2O to test various schemes for the production of magma by the fusion of the lower crust. Consideration of this system in conjunction with field and petrographic data indicates that perfect or nearly perfect fractional fusion is inadequate for obtaining most of the observed plutonic rocks. On the other hand, equilibrium fusion in repeated episodes corresponding to magmatic sequences defined by field, petrologic, and geochronologic data seems to fulfill all requirements imposed by the observed rock sequences. Fractional crystallization of the crystal-liquid mush generated by equilibrium fusion coupled with periodic upward or lateral movement of the less crystallized central parts of the magma would produce the characteristic mafic-to-felsic sequences. Radioactivity decay plus normal heat flow from the mantle do not now appear capable of producing enough heat to cause partial fusion of the lower crust, but upward transport of andesitic and basaltic magmas, possibly generated along a Mesozoic subduction zone, could have provided the required triggering heat.

Geochronology of Alaska–Aleutian Range batholith

A study of the geochronology and chemistry of the Alaska-Aleutian Range batholith by B. L. Reed and M. A. Lanphere indicates that the Mesozoic and Cenozoic plutonic rocks in an area of approximately 25,000 sq mi in south-central Alaska were emplaced during three discrete intrusive epochs. The oldest intrusive epoch is Early and Middle Jurassic and contains plutonic rocks emplaced between about 175 and 155 m.y. ago. During the Late Cretaceous and early Tertiary, plutonic rocks were emplaced between about 75 and 55 m.y. ago. Middle Tertiary plutonic rocks yielded potassium-argon ages ranging from about 40 to 25 m.y.

Evaluation of published radiometric ages from batholiths in the circumpacific part of North America indicates that the timing and duration of intrusive episodes are not as broadly contemporaneous as other workers have suggested. Reed and Lanphere recognize no more than three intrusive epochs in the Sierra Nevada-southern California batholith data of J. F. Evernden and R. W. Kistler (1970), and these do not correlate with the three intrusive epochs in the Alaska-Aleutian Range batholith.

Chemical data for the plutonic rocks show systematic variations across the Alaska-Aleutian Range batholith. The most pronounced variations are shown by K_2O, which decreases toward the side of the batholith closest to the Pacific Ocean, and Al_2O_3, which increases in that direction. These chemical trends are compatible with the hypothesis that presently exposed parts of the batholith are the eroded deeper parts of volcanic arcs and that magma generation took place along or above descending oceanic plates.

Grouping of peridotite-gabbro complexes

E. D. Jackson and T. P. Thayer (1972) have proposed that the three major, worldwide descriptive classes of peridotite-gabbro complexes—stratiform, concentric, and alpine—may be distinguished on the basis of geologic setting, kinds and proportions of rocks, mineralogy and texture, structure and form, thermal effects, and economic mineral deposits.

Stratiform complexes are very diversified; harzburgite, orthopyroxenite, websterite, norite, and anorthosite are characteristic, and lherzolite and wehrlite are rare. Cumulus textures are dominant; layers are concordant and of extreme lateral extent, and cyclic stratigraphy is well developed. Stratiform complexes have floors and high-grade metamorphic aureoles. Mineral deposits include high-chromium to high-iron chromite, titaniferous magnetite, and nickel-platinum sulfides.

Concentric complexes typically consist of dunite, wehrlite, hornblende pyroxenite, and two-pyroxene gabbro; lherzolite, harzburgite, and anorthosite are rare to absent. Cumulus and mush flow textures are dominant, although tectonite fabrics are known; lineate lamination is common, and layers, where present, are subparallel to discordant. Concentric complexes tend to be cylindrical with major units arranged concentrically. Wallrocks may be highly metamorphosed. Economic or potential mineral deposits include platinum and magnetite.

Alpine complexes are characterized by dunite, harzburgite or lherzolite, olivine gabbro, and gabbro; norite and anorthosite are rare. The rocks generally have tectonite fabrics; gneissic foliation and lineation are characteristic. Layers are lenticular, irregular, commonly discordant, and tightly folded. Contact metamorphism is generally slight to obscure; many complexes are fault bounded. Magmatic deposits consist of high-chromium to high-aluminum chromite. Alpine peridotites have been subdivided into harzburgite and lherzolite types. The apparent scarcity of alpine complexes older than 1,200 m.y. leads Jackson and Thayer to speculate that ocean floor spreading was considerably less active prior to that time.

Stability of biotite

The stability of annite has been reinvestigated by D. R. Wones, R. G. Burns, and Beverly Carroll (1971), and systematic relations have been established which show the effects of pressure and temperature on the physical properties, composition, and stability of annite. The results demonstrate that biotite solid solutions are essentially ideal; the experimentally determined stabilities can be described by a simple analytical function. Application of these results to plutonic rocks in a variety of geologic settings implies that most magmas only reach water saturation after extensive crystallization.

Alkaline border of Okanogan gneiss dome, northern Washington

Mapping by K. F. Fox, Jr., and C. D. Rinehart in the Mount Bonaparte quadrangle has revealed the presence of a strip of monzonitic and dioritic gneiss about 7 mi long and up to one-half of a mile in width bordering the northeastern contact of the Okanogan gneiss dome (Fox and Rinehart, 1971). The border gneiss resembles a strip of monzonitic and syenitic gneiss 10 mi long that is located along the same contact 8 mi to the west, which was described by A. C. Waters and Konrad Krauskopf (1941, p. 1398 1405) as the Osoyoos-Colville-greenstone hybrid syenite. A third strip of shonkinitic and syenitic gneiss about 1 mi long lies 4 mi farther northwest, athwart the 49th parallel and on line with the other two. Thus, three segments of the northern and eastern contact of the gneiss dome, aggregating 18 mi in length, are bordered by alkalic gneiss.

Two compositional trends have been discerned in the border gneiss: (1) The ratio of potassium feldspar to plagioclase increases progressively along strike toward the west—plagioclase is absent at the west end and (2) the color index decreases as silica increases southward across the strike of the belt, and accessory quartz is present adjacent to the contact with the gneiss dome.

The border gneiss has a conspicuous curving foliation imparted by the subparallel orientation of shiny black hornblende crystals, which are set in a chalky white aggregate of the felsic constituents. In certain areas, however, the foliation is interrupted by thin anastomosing zones of shear or cataclasis. The gneissosity, within the intervening lenticular or wedge-shaped areas, curves and feathers into the bounding shear zones. This festoon structure is probably the result of repeated cycles of failure by shear, plastic flow, and recrystallization accompanying spasmodic emplacement of the gneiss dome to the south.

To the north, the border gneiss interdigitates with and grades into the low-grade metamorphic rocks of the Anarchist Series suggesting that the gneiss is a product of metasomatic conversion of the Anarchist. No explanation can be offered at this time for the markedly alkalic character of this metasomatism, but it is probably significant that the border gneiss is approximately coincident with an east-southeast-trending belt of alkaline intrusive complexes (U.S. Geological Survey, 1968, p. A102), which include the well-known Kruger malignite (D. D. Campbell, 1939).

Trace element contents of Sierra Nevada granitic rocks

Trace-element analyses made prior to 1971 on plutonic rocks of the Sierra Nevada batholith, summarized by F. C. W. Dodge (1972), show that, in general, average abundances of elements determined are similar to abundances in high-calcium granites of the earth's crust. Average data for 20 elements were studied, and some other data were examined for an additional 26 elements. Lateral changes across the central Sierra Nevada batholith are well defined for beryllium, uranium, thorium, and rubidium, all systematically increasing eastward. Other trace elements exhibit less convincing trends of lateral variation. Causes of lateral variations of the trace elements are incompletely known but are undoubtedly related to compositional changes of major chemical constituents, particularly K_2O. The trends may be a reflection of crustal chemical variation which existed prior to batholith emplacement.

Iron dike and Table Mountain flows re-analyzed

New rock analyses obtained by George Phair on five samples of the Table Mountain flows, near Golden, Colo., and on six samples of the 37-mi-long Iron dike have led to a reclassification of these rock units and to a reexamination of their place in Laramide petrogenesis. The so-called basalt flows of North and South Table Mountains turn out to be latites quite close to the composition of Nockold's "average latite." Approximate plutonic analogs of these flows are found among the coarse-grained monzonite stocks of the Front Range that make up the relatively deep seated, early potassic subseries of George Phair and F. G. Fisher (1962).

The Iron dike is considered by most geologists to have been a precursor of the Laramide Intrusive sequence and by some to have been the magmatic progenitor of the sequence. The new analyses indicate that the dike has a bulk composition considerably lower in CaO and MgO than Nockold's "average tholeiitic basalt" and slightly lower in Na_2O and SiO_2 than Nockold's "average tholeiitic andesite." The relatively high TiO_2 (3.1 percent) in the new analyses contrasts strongly with earlier analyses (E. E. Wahlstrom, 1956) where TiO_2 was reported as ranging from 0.73 to 0.74 percent in four samples. X-ray fluorescence and quantitative spectrography have been used to confirm the new and higher TiO_2 values. The low TiO_2 values in the old analyses introduced a compensating error of Al_2O_3 that had a substantial effect on the SiO_2/Al_2O_3 index.

Quartz syenites and granites of the Pikes Peak batholith

The fayalite-bearing and fayalite-free quartz syenite, fayalite granite, and riebeckite granite of the Pikes Peak batholith, Colorado Front Range, investigated by Fred Barker, show a well-defined sodic trend on the normative quartz-albite-orthoclase diagram. These rock types probably were formed by differentiation of a parent magma of quartz syenitic or silica-poor granitic composition. The fayalite quartz syenite and fayalite granite have similar mineralogies including manganian fayalite, ferrohedenbergite, annite, and ferrohastingsite; alkali feldspar becomes more potassic with increasing silica. When the parent magma differentiated to about 72 percent SiO_2, however, the partial pressure P_{H_2O} reached a value at which fayalite became unstable and riebeckite-arfvedsonite appeared. Normative quartz, albite, and orthoclase, of the

predominant fayalite-free granite of the batholith, plot in a more potassic and siliceous part of the ternary diagram in spite of the fact that this rock contains even less normative anorthite than the fayalite-bearing granite. A slightly different mode of origin is indicated—probably one involving zone-melting into potassic roofrocks.

Studies by D. R. Wones and Barker of the compositions of these rocks, their annitic biotites, and their subassemblages of other mafic minerals, as well as comparison with artificial systems, indicate that the Pikes Peak batholith's intrusives crystallized at temperatures of about 850° to 700°C, at P_{H_2O} of about 1,200 bars or less, at P_{total} mostly greater than P_{H_2O}, and at oxygen fugacities close to those of the quartz-fayalite-magnetite buffer.

METAMORPHIC ROCKS AND PROCESSES

Carbonaceous material changes to graphite in prograde metamorphism

Carbonaceous material in coals and pelitic rocks of Pennsylvanian age from Rhode Island and from the Worcester area, Massachusetts, has been studied by E. S. Grew using X-ray diffraction and chemical analyses of the separated material. The results show that, as the enclosing rocks pass from the chlorite zone through the almandine and kyanite-staurolite zones to the sillimanite zone of metamorphism, the carbonaceous material becomes progressively better crystallized, so that the X-ray pattern becomes sharpened and more diffraction lines appear. Diffuse two-dimensional (*hk*) bands are resolved into the three-dimensional (*hkl*) lines of graphite; the (*hkl*) lines also become sharper. The principal loss of volatiles apparently occurs in the chlorite zone and is accompanied by the appearance of (112) and (114) lines of graphite. Completely ordered graphite, instead of disordered graphitelike material, is restricted to the sillimanite zone. Concomitantly, the hydrogen and nitrogen contents of the carbonaceous material decrease, so that in the sillimanite zone there is only 0 to 0.1 percent hydrogen or nitrogen.

Distinction of gabbro and metagabbro from mafic metavolcanic rocks in ophiolitic suites

Many alpine peridotites contain associated mafic gneisses which may be interpreted either as basaltic volcanic rocks metamorphosed by the peridotite or as metagabbros comagmatic with the peridotite. T. P. Thayer has cited several lines of evidence that bear on this problem. Studies of unmetamorphosed peridotite and gabbro associations show that these rocks are often intricately interlayered. Similar interlayering of amphibolites, granulites, and peridotites would not be unexpected in metamorphosed peridotite-gabbro complexes. Also, it has not been demonstrated that contact metamorphism of basaltic country rock of peridotite would result in such an intricate interlayering. Compositional differences between alpine gabbros and basalts are quite distinct if the rocks have not been altered. Metasomatic alteration of gabbros, however, apparently shifts the Mg:Fe and Ca:Na ratios of gabbros toward those of basalts, so that it is difficult to determine the origin of these rocks solely on the basis of bulk chemical composition.

Pipelike skarns at Big McGee Lake, Mono County, California

B. A. Morgan has studied small pipelike skarns in the area of Big McGee Lake, Mount Abbot 15-minute quadrangle in Mono County, Calif. These skarns are found sporadically along the contact between the Cretaceous Round Valley Peak Granodiorite and the Bloody Mountain Formation of Permian age. Metasomatic replacement of the Bloody Mountain Formation is in the form of small pipelike bodies which project away from the plutonic contact and into the calc-silicates. Traversing from the margin of a pipe into the core, the skarn frequently is surrounded by a narrow rim of wollastonite. Then an invariable thick dark-green shell of salite-quartz is found with the pyroxene having an average composition of Di_{75}–Hd_{25} (diopside-hedenbergite). This gives way to an irregular pyroxene-garnet zone and then to a core of nearly monomineralic garnet having a composition of about And_{50}–$Gross_{50}$ (andradite-grossularite). Along most of the exposed lengths of the pipes the skarn shows little evidence of retrograde reactions; along the skarn-granodiorite boundary, however, the pyroxene-garnet minerals are replaced by epidote and by epidote-amphibole-sphene-calcite-quartz masses. The absence of wollastonite and plagioclase within the skarns and the evident retrograde reactions of garnet to epidote allow a very qualitative use of equilibria in the system CaO–Al_2O_3–SiO_2–CO_2–H_2O. These equilibria indicate that the skarn was derived in equilibrium with a water-rich fluid containing from 10 to 30 mole percent CO_2. Assuming a total pressure of 2 kb, the temperature of formation of the garnet-pyroxene assemblages should be in the general range of 650° to 600°C and retrograde reactions should be on the order of 75° to 100°C lower than the temperature of formation.

GEOTHERMAL SYSTEMS

Hot-water and vapor-dominated geothermal systems

D. E. White, L. J. P. Muffler, and A. H. Truesdell (1971) have found that vapor-dominated (dry-steam) geothermal systems are uncommon and poorly understood compared with hot-water systems. Critical physical data on both types were obtained from USGS research in Yellowstone Park. Vapor-dominated systems require relatively potent heat supplies and low initial permeability. After an early hot-water stage, a system becomes vapor-dominated when net discharge starts to exceed recharge. Steam then boils from a declining water table; some steam escapes to the atmosphere, but most condenses below the surface where its heat of vaporization can

be conducted upward. The main vapor-dominated reservoir actually is a two-phase heat-transfer system. Vapor boiled from the deep (brine?) water table flows upward; most liquid condensate flows down to the water table, but some may be swept out with steam in channels of principal upflow. Liquid water favors small pores and channels because of its high surface tension relative to that of steam. Steam is largely excluded from smaller spaces but greatly dominates the larger channels and discharge from wells. With time, permeability of water-recharge channels, initially low, becomes still lower because of deposition of carbonates and $CaSO_4$ which decrease in solubility with temperature. The "lid" on the system consists in part of argillized rocks and CO_2-saturated condensate.

This model of vapor-dominated systems and the thermodynamic properties of steam provide the keys for understanding why the major reservoirs of The Geysers, Calif., and Larderello, Italy, have rather uniform reservoir temperatures near 240°C and pressures near 34 kg/cm^2 (absolute; gases other than H_2O increase the pressures). Local supply of pore liquid and great stored heat of solid phases account for the physical characteristics and the high productivity of steam wells.

White, Muffler, and Truesdell suggest that vapor-dominated systems provide a good mechanism for separating volatile mercury from all other metals of lower volatility. Mercury is likely to be enriched in the vapor of these systems; the zone of condensation that surrounds the uniform reservoir is attractive for precipitating HgS.

A more speculative suggestion is that porphyry copper deposits form below the deep water tables hypothesized for the vapor-dominated systems. Some enigmatic characteristics of these copper deposits are consistent with such a relationship and warrant consideration.

Hydrothermal alteration of ash-flow tuff in a vapor-dominated geothermal system

X-ray diffraction and petrographic studies by L. J. P. Muffler and K. E. Bargar on core from research drill hole Y-11 in the Mud Volcano area of Yellowstone Park have revealed a surprisingly complex alteration pattern. At depths less than 58 m the hydrothermal minerals are montmorillonite, pyrite, and β-cristobalite, with sporadic kaolinite, gypsum, and calcite. At depths of 58 m to the hole bottom at 106 m, the hydrothermal minerals are chalcedony, quartz, montmorillonite, septechlorite, and quartz, with sporadic calcite, rhodochrosite, fluorite, mordenite, and kaolinite. Initial interpretation suggests that this complexity reflects the presence of both water and steam in the geothermal system and the change in time from a hot-water geothermal system to a vapor-dominated geothermal system.

Geochemical prospecting for hot-water geothermal reservoirs

R. O. Fournier and A. H. Truesdell are evaluating geochemical techniques used as prospecting aids for geothermal energy. They found that erratic results are obtained using the simple ratio Na:K as a geothermometer because Ca^{+2}, as well as Na^+ and K^+, is important in many controlling reactions in the natural systems. Using data on subsurface water compositions and temperatures in geothermal wells, the effect of Ca^{+2} was investigated by plotting the log of an approximation of the equilibrium constant K^* versus T^{-1} ($^\circ K^{-1}$) for various reactions, assuming constant aluminum and excess silicon. To facilitate comparison, all data were transposed to the general form $\log K^* = \log (Na/K) + \beta \log (Ca^{1/2}/Na)$, where β is fixed by the stoichiometry of the particular reaction. An empirical method of evaluating β was found so that a calcium correction can be made that greatly improves the accuracy of temperatures estimated from alkali ratios in most natural waters.

Physical chemistry of geothermal waters

A. H. Truesdell has completed a computer program which calculates the physical and chemical properties (temperature, pressure, gas partial pressures, water-steam ratio, water composition and ion pairing, and pH) of fluids in geothermal aquifers from analyses of produced steam and water, measured enthalpy (heat content) and stored values for the thermodynamic properties of steam and water, dissociation constants of ion pairs and weak acids, and solubility constants of gases. For geothermal fluids from New Zealand, Chile, and Turkey, the measured surface pH values range from 7.3 to 9.0 with most near 8.3. The calculated aquifer pH values for these waters range from 5.7 to 7.8 with most values near 6.5. If waters with excess steam resulting from production are excluded, the aquifer pH values are all below 7.0. Aquifer Na^+/H^+ and K^+/H^+ ratios and aquifer pH values indicate buffering with aluminosilicates rather than with solution buffer pairs.

Seismic noise in a geothermal area

There is considerable speculation and some vague evidence indicating the possibility that the seismic noise field in a geothermal area may have higher than average amplitudes in the 1- to 10-Hz frequency band. Since seismic noise is generated by a variety of sources, the first step in identifying seismic noise of geothermal origin is to design an experiment by which not only the amplitude variation of the noise but also spectral variations, velocity, and direction of travel can be calculated. Such an experiment was conducted by H. M. Iyer in The Geysers geothermal area, California. Seismic arrays were operated in seven different locations in the area, and the data were recorded on magnetic tapes using analog and digital techniques in the analysis. The main conclusions so far are the following: (1) There are two peaks in the noise spectrum around 1 Hz and 3 Hz, respectively, and (2) the energy levels of these peaks show strong regional variation.

SEDIMENTARY ROCKS AND DIAGENETIC PROCESSES

Harmotome from lacustrine tuffs

During an investigation of the Big Sandy Formation (Pliocene) near Wikieup, southern Mohave County, Ariz., R. A. Sheppard and A. J. Gude III recognized harmotome in thin altered tuffs. Harmotome, probably the most common of the barium-rich zeolites, is rarely found in sedimentary rocks. Harmotome formed in the lacustrine Big Sandy Formation during diagenesis and is associated with a variety of authigenic zeolites and clay minerals. Chemical analysis of the harmotome gave a formula of

$$Na_{1.46}K_{0.65}Ba_{0.78}Sr_{0.01}Ca_{0.16}Mg_{0.51}Al_{4.04}Fe^{+3}_{0.54}Si_{11.31}O_{32}\cdot 11.23H_2O.$$

This harmotome is the most alkali-rich and barium-poor harmotome thus far reported and can be derived from ideal harmotome by $Na_2(K_2)$ replacement of Ba(Sr,Ca,Mg) and $Na(K)Al(Fe^{+3})$ replacement of Si. The mean index of refraction is 1.506 and the monoclinic cell parameters are a=9.92±0.004 A, b=14.135±0.009 A, c=8.685±0.006 A, β=124°55±2′, and V=998.59±0.76 A^3.

Iron content of dolomites

Dolomites in California Tertiary sediments contain as much as 17 mole percent $FeCO_3$; most have less than 2 mole percent because of the generally low concentration of soluble iron in reduced pyrite-bearing sediments that were invaded by meteoric water, according to K. J. Murata (Murata and others, 1972). The iron content of California dolomites thus has an interesting connotation of time, pointing to a post-organic period of formation for the iron-rich samples.

Formation of beidellite during weathering

Z. S. Altschuler and E. J. Dwornik have found that, upon exsolution of goethite during the alteration by ground waters of green nontronitic montmorillonite in the Bone Valley Formation of Florida, the residual clay retains the structure of montmorillonite and is probably an aluminous member of the group, close to beidellite. Bleached patches of such clay are found to exhibit a change in morphology, entailing a replacement or a segmentation of the sheetlike flakes of the nontronitic montmorillonite into thin, lathlike sectors, resembling the crystals and cleavage fragments that characterize beidellite. Small white fracture fillings adjoining the weathered zones are found to consist mainly of such thin lathlike clay particles. This appears to be a very rare instance of beidellite newly precipitated from solution or physically translocated from adjoining, newly formed material.

GEOCHEMISTRY OF WATER

The primary objectives of geochemical studies in hydrology are (1) to understand the hydrochemical processes that control the chemical character of water, (2) to increase understanding of the physics of the flow system by application of geochemical principles, and (3) to understand the rates of chemical reactions and rates of transport of physical and chemical masses within the hydrologic system.

Chromatographic analyses of soil gases

D. W. Fisher has developed a method by which the major constituents of many soil gases can be determined by a relatively simple two-step chromatographic analysis. Concentrations of argon, oxygen, nitrogen, carbon dioxide, and nitrous oxide can be determined quantitatively in 50-ml gas samples at total pressures as low as 5 cm of mercury. Satisfactory separations of argon, oxygen, and nitrogen are achieved in 12-ft columns of molecular sieve 5 A at 0°C; good separation of carbon dioxide and nitrous oxide is attained with 6-ft Porapak Q columns at 25°C. Helium is used as the carrier gas, and a thermal conductivity bridge serves as the detector for the separated component gases.

Several gas samples were collected by C. T. Rightmire for an investigation of stable isotope variations at increasing depths in the soil. Chromatographic analyses of the soil gas components showed patterns of changing concentrations of oxygen and carbon dioxide; knowledge of these patterns should be useful in interpretation of the stable isotope and other geochemical data.

Weathering of Pahala Ash in Hawaii

Results of studies of the weathering of Pahala Ash and related units by B. F. Jones (USGS) and R. L. Hay (Univ. California, Berkeley) indicated that ash alteration was closely correlated with age and rainfall. Products vary from amorphous materials and gibbsite to montmorillonite and calcite. Comparative analyses of fresh and weathered material suggested much more leaching than did computations of pore-water composition, rainfall, and the age of the ash. Clay-mineral stabilities calculated from pore-water analyses roughly corroborated mineral occurrence.

Abert and Summer Lakes, Oregon

Fine-grained lacustrine deposits that underlie saline, closed-basin Abert and Summer Lakes and adjacent playas harbor large solute tonnages, according to A. S. Van Denburgh. Beneath the lakes, interstitial brines constitute as much as 85 percent of the muds, by volume. Measured salinities at depths of 2 to 5 ft are 40,000 to 50,000 ppm beneath Summer Lake, and they exceed 100,000 ppm beneath much of Lake Abert. The interstitial solutes are dominated by sodium among the

cations and are richer in carbonate plus bicarbonate and poorer in chloride than the overlying lake waters. Characteristic ratios of chloride to sodium (expressed in equivalents per million) are 0.25 to 0.30 for brines beneath Summer Lake and about 0.50 for those at Lake Abert. Ratios for the lakes themselves are about 0.35 for Summer Lake and 0.55 for Lake Abert.

Further analysis of sediments by B. F. Jones from alkaline saline Abert and Summer Lakes, Oreg., disclosed local abundances of calcite and phillipsite, presumably detrital. Clinoptilolite appears to be an ubiquitous constituent of the coarser clay, as is a nonphillipsite, 7-A component requiring further definition. The mixed-layer montmorillonite characteristic of the fine-clay fraction is trioctahedral, has apparently as much as a 35-percent 10-A component, and may be interlayered with hydrated silica.

Abraham Lerman (Northwestern Univ.) and B. F. Jones (USGS) developed a model for the diffusion of salts between interstitial brines and overlying lake waters. The model also considers sedimentation and water flow out of the sediment. It satisfactorily predicted rates of salt transport from pore brines into more dilute lake waters of Lake Abert and indicated that nearly half of the dissolved salt content of the lake in 1963–64 was provided by diffusion from the sediment pore space during the preceding 25 yr.

Artificial recharge on southern High Plains

Specific-ion electrodes were used by W. W. Wood to simultaneously determine the activity changes of calcium, hydrogen, sodium, fluoride, and divalent ions when a calcareous clay was batch-mixed with waters of different chemical quality. When the clay was mixed with treated Canadian River water (Lubbock tapwater) containing 220 mg/l sodium, the calcium and magnesium were displaced from the clay; the exchanged calcium precipitated as calcium carbonate whereas the magnesium remained in solution. The pH decreased rapidly. Fluoride entered into both a rapid and long-term reaction. The reactions for all observed ions other than fluoride in this solution were faster than the response time of their electrodes and were nearly complete in 1 min.

Reactions of a duplicate sample of the clay with distilled water were also very rapid but required several minutes before equilibrium was attained. The clay mixture with distilled water appeared to be a mineral-solution reaction as opposed to an ion-exchange reaction for most of the measured constituents in the tapwater-clay environment. The results of these and other tests suggest that some important water-rock reactions can be considered nearly instantaneous for purposes of digital modeling of the geochemical changes during artificial recharge.

Relation of chemical character of ground water to faults

Results of investigations by R. E. Faye of ground-water quality in northern Napa Valley, Calif., indicated that high sodium and high bicarbonate waters are associated with the Knoxville-Horsetown marine sediments of Jurassic-Cretaceous age. Commonly, these waters also contain relatively high concentrations of calcium, sulfate, and boron. A thermal water having high concentrations of sodium, chloride, and boron was found in close proximity to fault zones. The occurrence of this water in springs and wells may indicate the location of faults beneath undisturbed formations.

Microbiological ecology of ground water

In studies of the importance of bacteria in the clogging of recharge wells M. M. McReynolds and G. G. Ehrlich investigated spectrophotometric methods for the determination of cytosine plus guanosine (C+G) content of deoxyribonucleic acid derived from ground-water-inhabiting bacteria. Such information is useful for the identification and differentiation of bacteria. Of several methods studied, the Fredericq-Oth-Fontaine ultraviolet photometric method gave the best results. Several species of bacteria in the genus *Pseudomonas* (58 to 70 mole percent C+G) were tested. Results of most tests were within ±3 mole percent C+G of values found by other methods for the same species. The precision of the method is less than that of either the sedimentation or thermal denaturation methods commonly used. It can be used for intergeneric differentiation in favorable cases but is too imprecise for detailed intrageneric differentiation.

Dissolved organic carbon

A nationwide study, under the direction of R. L. Malcolm, of dissolved organic carbon (DOC) in ground water was conducted at 100 sites in 27 States to find base levels of naturally occurring dissolved organic materials in ground water. Concentrations ranged from 0.1 to 15.0 mg/l with an overall average of 1.2 mg/l. DOC concentrations were highly correlated with conductivity and alkalinity but not with pH. The average DOC concentrations for various types of aquifers increased in the order: fractured igneous and metamorphic hardrock <sandstone <deep unconsolidated sediments <shallow unconsolidated sediments <limestone. DOC was determined to be a useful parameter in the evaluation of aquifer contamination by organic substances during deep-waste-disposal activities.

Solubility of aluminum

J. D. Hem synthesized an aluminosilicate with the composition of halloysite in the laboratory by mixing dilute solutions of aluminum and silica at 25°C. From pH 4 to 10 it had a well-defined and reversible solubility after a few months of aging, equivalent to a ΔG° of −897±1 kcal per mole. The solid was amorphous to X-rays, but electron micrographs and electron diffraction revealed many very small, poorly formed crystals. Similar material was recovered from river water and

appears likely to be a control over aluminum solubility in natural water.

The dissolved-aluminum content of stream water has been difficult to determine in the past because suitable methods of sufficient sensitivity were rarely available. V. C. Kennedy and G. W. Zellweger modified prior methods for determining aluminum in solution to achieve a detection limit of 1 μg/l. Results of application of the method to waters from five small streams west of San Francisco Bay and to the Mattole River of northern California suggest that aluminum concentrations for such streams commonly range 2 to 15 μg/l during periods of low flow.

Nonmeteoric waters associated with mercury deposits

In most active geothermal systems, the isotopic D/H (deuterium/hydrogen) ratio of the hot water is nearly identical to that of the local cold meteoric water, proving an overwhelming dominance of meteoric water in the systems, but the O^{18}/O^{16} ratio has been shifted to more positive values because of subsurface exchange with rocks initially high in O^{18}. D. E. White, Ivan Barnes, and J. R. O'Neil have recognized thermal and mineral waters associated with mercury deposits of the California Coast Range that differ from this pattern. Some waters are enriched in δD by as much as 40‰ and in δO^{18} by as much as 13‰ relative to local meteoric waters. The δD enrichment, the chemical compositions (high in CO_2, B, and NH_3 and some in Cl), and ridgetop discharge require large proportions of nonmeteoric water. The data strongly support previous conclusions that these unusual spring waters are connate and metamorphic in origin, being derived from reaction of ancient ocean waters with marine sediments and now being forced out by pressures that are in part lithostatic.

CO_2-rich waters are found along the west coast of North America in the coastal geochemical province in lithologies which include chert, greenstone, graywacke, and ultramafic rocks and their altered equivalents. Reactions of the CO_2-rich waters with fresh ultramafic rocks yield magnesite deposits, and reactions of the CO_2-rich waters with serpentinite yield a silica-carbonate rock composed of opaline silica and magnesite. Although many mercury deposits are found in silica-carbonate rock, mercury concentrations found in the CO_2-rich waters are 3 μg/l or less. The fluids that cause the wallrock alteration of the mercury deposits are not necessarily the ore-forming fluids.

WATEQ extended

The computer program, WATEQ, developed by B. F. Jones and A. H. Truesdell for calculating solute species distribution and ion activity products from water analyses now includes error estimates on stability constants for many of the minerals considered. After the developers experienced much difficulty computing estimates of reduced sulfur and nitrogen species from oxidized forms and Eh, the program was extended to calculate probable errors for these Eh couples and to compare them with measured values. Molar ratios from the original analyses and ratios of constituent activity are also computed.

ISOTOPE AND NUCLEAR GEOCHEMISTRY

ISOTOPE TRACER STUDIES

Geochemistry of trondhjemites

Geologists are becoming increasingly aware of the importance of trondhjemitic, plutonic, and metamorphic rocks in early Precambrian terranes, especially those 2.7 b.y. or older. Such rocks are much more abundant in the Precambrian than in the Phanerozoic, and furthermore their positions in individual plutonic sequences indicate that an understanding of their origin is crucial to crustal formation and evolution. A continuing investigation by Fred Barker, Z. E. Peterman, and H. T. Millard, Jr., involves determination of major and trace element compositions and strontium isotope ratios in a suite of more than 15 trondhjemites of both Precambrian and Phanerozoic age and of worldwide distribution. Some gneissic trondhjemites are metamorphosed volcanic rocks of rhyodacitic composition (Fred Barker and others, 1969); others are clearly intrusive and may exhibit compositional variations that are readily explained by simple fractional crystallization of intermediate magmas.

Preliminary strontium isotopic measurements indicate that some trondhjemites were derived from the mantle either directly or by fractionation of a more mafic mantle-derived parent. There is no evidence that any of the trondhjemites studied were derived by partial or total fusion of graywackes as suggested by some petrologists. Although all trondhjemites, regardless of origin, are similar in major element composition, trace element concentrations may afford a means of genetically classifying these rocks. Both rubidium and strontium contents and rare earth distributions appear to be promising in this respect. Most intrusive trondhjemites are characterized by high strontium contents—usually greater than 500 ppm. Trondhjemites associated with ophiolites and perhaps those in shallow arc environments contain less than 200 ppm strontium like the associated low-potassium tholeiites. Many of the rocks in the intermediate range may be metamorphosed calc-alkaline volcanic rocks. By identifying the different types of trondhjemites and relating these to known tectonic settings, it should be possible to reconstruct the early phases of continent formation.

Plutonic geochronology of eastern Massachusetts

In a study by R. E. Zartman, uranium-thorium-lead zircon

isotopic ages along with other radiometric data are found to reveal two major episodes of igneous activity in eastern Massachusetts—one occurring in late Precambrian time (600–650 m.y. ago) and the other in Ordovician time (435–470 m.y. ago). In contrast, the Early to Middle Devonian Acadian orogeny does not seem to have contributed significantly to the volume of igneous rock in the eastern third of the State.

The Dedham Granodiorite, the Milford and Northbridge Granites, and some plutonic rocks from north of Boston give late Precambrian ages. Field relationships require that associated gabbro-diorite as well as the Westboro Quartzite, Marlboro Formation, and other high-grade metamorphic rocks intruded by these igneous rocks are also Precambrian. During the Paleozoic, this terrane, which includes much of southeastern Massachusetts and probably Rhode Island, remained relatively inactive although restricted plutonism and volcanism together with pervasive, low-grade metamorphism did occur.

Ordovician ages were obtained on the Ayer Granite and the Newburyport Quartz Diorite. These plutonic rocks crop out in an arcuate belt extending from Worcester through Lowell to the coast at Newburyport. Together with adjacent metasedimentary rocks, they may occupy a tectonic slice caught between a stable massif to the southeast and the area of major Acadian deformation in central Massachusetts and New Hampshire. The juxtaposing of formerly separate tectonic elements probably took place during the Acadian orogeny with some further adjustments occurring in late Paleozoic time.

California granitic rocks

Initial Sr^{87}/Sr^{86} of granitic rocks, representing the entire 130-m.y. timespan of emplacement during the Mesozoic, exposed north of the Garlock fault in California ranges from 0.7031 to 0.7094 as determined by R. W. Kistler and Z. E. Peterman. A systematic areal variation, independent of age, exists for initial Sr^{87}/Sr^{86} in these granitic rocks and is the same as the areal variation in initial Sr^{87}/Sr^{86} of superjacent late Cenozoic basalts and andesites.

Two values of initial Sr^{87}/Sr^{86}, 0.7040 and 0.7060, mark natural separations of granitic rock data on potassium-rubidium, potassium-strontium, and rubidium-strontium variation diagrams and also, when contoured, seem to represent geographic markers of paleogeographic, geochemical, and physiographic significance. Late Precambrian sedimentary and metamorphic rocks in California occur only in the region where initial Sr^{87}/Sr^{86} of granitic rocks is greater than 0.7060. The initial line representing $Sr^{87}/Sr^{86}=0.7060$ is approximately coincident with the boundary between Paleozoic eugeosynclinal and miogeosynclinal rocks. Granitic rocks intruded into Paleozoic miogeosynclinal rocks have initial Sr^{87}/Sr^{86} greater than 0.7060, while those intruded into eugeosynclinal Paleozoic rocks have initial Sr^{87}/Sr^{86} less than 0.7060. The initial line representing $Sr^{87}/Sr^{86}=0.7040$ is the eastern limit of principal exposures of ultramafic rocks, the western limit of Cretaceous granitic rocks, and is coincident with an abrupt change in "topographic expression" on the Bouguer gravity map of California.

Parent magmas of the majority of granitic rocks investigated were derived in a region that was laterally variable in compositions and in a zone of melting that intersected both upper mantle and lower crust. Some igneous rocks in the region, however, such as Jurassic volcanics in wallrocks and roof pendants and some granitic rocks with high strontium concentrations and low rubidium-strontium ratios, suggest that deeper sources are also involved in the total spectrum of igneous rocks in the region.

Mantle evolution beneath the South and Central Pacific Basins

In the South and Central Pacific Basins, C. E. Hedge and Z. E. Peterman have shown that Sr^{87}/Sr^{86} values for oceanic island basalts increase progressively outward from the East Pacific Rise (Z. E. Peterman and C. E. Hedge, 1972). Basalts dredged from the East Pacific Rise are uniformly low in potassium and Sr^{87}/Sr^{86} (average 0.7025). Basalts from islands nearer the rise, though variable in composition, tend to be lower in potassium and in Sr^{87}/Sr^{86} values (0.7025–0.7035). The degree of silica undersaturation, rubidium and strontium contents, and rubidium-strontium ratios of most of the basalts also increase away from the rise. These correlations suggest chemical and isotopic variations in the upper mantle that occur in a geometrically systematic fashion parallel to the linear zone of crustal divergence where new oceanic crust is being formed by intense magmatic activity.

The data place certain limits on acceptable models for the source region of these island basalts though, in themselves, they do not allow a unique interpretation of the long-term mantle evolution. The pattern of Sr^{87}/Sr^{86} values increasing outward from the East Pacific Rise indicates that the mantle may have been zoned, for a long ($\geq$ 1.5 b.y.) period of time, before the onset of the current episode of upwelling beneath the rise.

Search for older rocks in the Black Hills

Studies have shown that the isotopic composition of lead in Cenozoic ore deposits may be useful in providing information on the age of the oldest crustal rocks present. As an additional test of this hypothesis, a cooperative lead isotope investigation of galenas from Cenozoic ores of the Black Hills, S. Dak., was undertaken by M. H. Delevaux and B. R. Doe (USGS) and by D. M. Rye (Univ. Minnesota).

In the Black Hills, Precambrian-X metasedimentary rocks are intruded by 1,750-m.y.-old granites and pegmatites. A few square miles of Precambrian-W granitic gneisses (2,500–2,600 m.y. old) crop out, and these were metamorphosed 1,750 m.y. ago. The Cenozoic ore leads indicate an integrated source age

of 1,930 m.y. using the Pb^{207}/Pb^{206} secondary isochron methods and assuming a mineralization age of 0 m.y., or 1,900 m.y. for a mineralization age of 60 m.y. This age is intermediate between the ages of the two Precambrian plutonic and metamorphic events as is commonly the case for polygenetic terranes. For example, the isochron age for the Late Cretaceous Boulder batholith of Montana is 2,200 m.y., whereas the proximal Precambrian are in the age groups of 1,000 to 1,800 m.y. and 2,700 m.y. or older. A galena sample from the Black Hills thought to be of Precambrian age fits a model for mineralization at 1,800 m.y. from a source of about 2,800 m.y. Thus, the existence of the oldest Precambrian rocks was observed in the lead isotopic data even though the rocks are not abundant at the surface.

These data have important applications to other areas. In Colorado, the oldest recognized Precambrian rocks are 1,700 to 1,800 m.y. old. These were extensively intruded by granitic rocks 1,400 to 1,500 m.y. ago. Cenozoic galenas from Colorado give a Pb^{207}/Pb^{206} secondary isochron age of 1,560 m.y., again intermediate between the ages of the two major recognized Precambrian events. By analogy with the lead isotope studies of the Black Hills and the Boulder batholith, it appears that there may not be Precambrian rocks in Colorado older than 1,700 to 1,800 m.y.

Younger ore leads in the Front Range

The Front Range of Colorado appears to be unique among the earth's Precambrian terrains for the magnitude and extent of the thorium and lead enrichment evident in its igneous rocks. In contrast, the uranium contents are reasonably normal. Accordingly it permits an evaluation of the role played by older radioactive source rocks on the isotopic evolution of associated younger ore leads, an evaluation not feasible in more normal uranium-thorium-lead environments.

Results of precise determinations of the lead contents of 62 samples of unaltered Silver Plume Granite and its correlation obtained by George Phair show consistently high lead contents (maximum 100 ppm) and very high lead-uranium ratios (maximum ≈50). The lead enrichment over that in normal crustal rocks is roughly comparable in scale to the thorium enrichment previously established by the sampling program. Approximately 90 percent of the contained Pb cannot be accounted for by the decay of the associated uranium and thorium. By reference to the work of B. R. Doe and S. R. Hart (1963), the nonradiogenic component is inferred to be old-age common lead localized largely in potassium feldspar during its crystallization 1,400 m.y. ago.

The presence of high levels of thorium and of old-age common lead in the Tertiary environment of the Silver Plume Granite helps to explain certain puzzling features of the ore leads studied by M. H. Delevaux and others (1966):

1. The unusually high ratio of thorium lead to uranium lead, Pb^{208}/Pb^{206}, in the Tertiary ore leads collected in and around batholiths of Silver Plume-type granite at Jamestown, Silver Plume, Urad, and Evergreen and in the Holy Cross quadrangle.
2. The unusually high Pb^{204} contents for such young leads; Pb^{204} is the index of common or nonradiogenic lead.
3. The unusually low Pb^{206}/Pb^{207} ratios of these Tertiary galena samples. Houterman's model ages are calculated to fall in the range 900 to 300 m.y., and all but one of the nine samples fall in the range 900 to 600 m.y.

STABLE ISOTOPES

Darwin deposit, California

The isotopic compositions of carbon and oxygen in calcite and sulfur in ore minerals and the ratio of deuterium to hydrogen in fluid inclusions in sphalerite were determined by R. O. Rye and W. E. Hall for the Darwin lead-zinc-silver deposits, California. The δC^{13} values of hydrothermal calcite range from -3.6 to -5.8‰ (PDB). These values suggest that the CO_2 in the ore fluid was from a deep-seated source. The δS^{34} values of all sulfide minerals range from +4.4 to -5.7‰. The different values of δS^{34} are consistent with a given mineral assemblage. The fractionation of S^{34} between sphalerite and galena is consistent and indicates that these minerals deposited in equilibrium at temperatures of approximately 330°C from a hydrothermal fluid with a δS^{34} of +2‰.

Homestake deposit, South Dakota

D. M. Rye (Univ. Minnesota) and R. O. Rye (USGS) have completed a stable isotope study of the Homestake gold deposit, South Dakota. The evidence indicates that the deposit is part of a Precambrian carbonate iron-formation and that the gold was part of the original sedimentary sequence. It had been commonly thought that the gold was introduced during the widespread Tertiary mineralization in the Black Hills. The δS^{34} values of arsenopyrite and pyrrhotite in the deposit show a very strong stratigraphic and facies dependence. The δS^{34} values range from 5.9 to 9.8‰ in the Homestake Formation, from 3.7 to 4.8‰ in the underlying Poor Man Formation, and average about 19‰ in the overlying Ellison Formation. The δO^{18} values of massive quartz range from 11.7 to 15.8‰ but show a strong dependence upon proximity to carbonates. This indicates that much of the quartz, commonly thought to be Tertiary, was present during Precambrian metamorphism. The δD values of water and CO_2 and H_2O:CO_2 ratios in fluid inclusions in the Homestake quartz and arsenopyrite are different from those in fluid inclusions of known Tertiary minerals. The δD and δC^{13} values in water and CO_2 in fluid inclusions range from -65 to -98‰ and -2 to -5‰, respectively. The H_2O:CO_2 ratios in these inclusions average about 2. On the other hand, the δD and δC^{13} values of inclusions in known Tertiary minerals average about -61‰ and -7‰, respectively, and H_2O:CO_2 ratios average 52.

Pasto Bueno deposit, Peru

G. P. Landis (Univ. Minnesota) and R. O. Rye (USGS) have completed a stable isotope study on the Pasto Bueno tungsten-sulfide deposit, northern Peru. The δD values of waters in fluid inclusions and hydrous minerals range from -30 to $-85‰$ and indicate that both deep-seated and meteoric waters were present in the ore fluids. Most of the sulfide deposition was associated with the deep-seated waters. All the tungsten mineralization, however, was associated with meteoric waters. The δO^{18} values of quartz do not show a correlation with the δD values of the inclusion fluids, and calculations based on the δO^{18} of quartz and filling temperatures of fluid inclusions indicate a constant value of about $6‰$ for the hydrothermal fluids for most of the paragenesis. Evidently, the mixing of deep-seated and meteoric waters took place at considerable depth, possibly in the magma-vapor system. The δS^{34} values of sulfur in the hydrothermal fluids averaged about $+2‰$. The δC^{13} values of the CO_2 in the hydrothermal fluids averaged about $-9‰$. The data suggest that both sulfur and carbon were from a deep-seated, possibly juvenile source.

Origin of Ordovician banded limestones, Nevada

R. J. Ross, Jr., and Irving Friedman have made oxygen and carbon isotope analyses of a banded Ordovician limestone located in Bodie, Nev. The results indicate that (1) the isotopic composition of the Ordovician sea was approximately $8‰$ lighter in O^{18} than the present-day ocean, (2) the bandings in these unusual rocks are not due to the filling of voids by later carbonate but are a replacement phenomenon that occurred soon after formation of the reef, and (3) the flanking beds formed in deeper water below the wave base. This latter conclusion is reached by the fact that the carbon isotopic composition is light and variable, whereas the reef, which is exposed to wave action and to a source of marine bicarbonate, has a very constant carbon isotope composition. The environment in which the flanking beds formed was one in which the carbon source was not that of the open ocean entirely, but there was also a contribution of organic carbon from decomposing organisms.

Isotope investigations in the Ruby Mountains, Nevada

J. R. O'Neil and R. W. Kistler have measured the isotope compositions of oxygen, strontium, and argon in a thrust-faulted igneous and metamorphic terrain in the northern Ruby Mountains, Nev. O^{18} analyses of unsheared quartz in the breccia zone and local ground water indicate that a minimum temperature of approximately 400° resulted from thrusting. The breccia quartz precipitated in isotopically light ground water, and limestone carbonates in and near the thrust zone were drastically lowered in O^{18} content by being heated in this water. The carbon isotope ratios of the carbonates retained their marine values showing that no new source of carbon (or exotic fluid) was added to the system.

Strontium and argon mobilization in adjoining granites and gneisses are directly related to the thrusting event. The oxygen isotope ratios in the minerals of these rocks, however, reflect a prior high-temperature metamorphism (with heavy δ values) and were unaffected by the thrusting event. Oxygen, strontium, and argon measurements show that the rocks were not equilibrated with one another but only within each rock type. This, and the failure to alter the oxygen isotope ratios, indicates that little or no water was involved in the strontium and argon equilibration. Thus, a rather narrow range of conditions is defined under which these processes can occur.

Oxygen isotope activities of brines at elevated temperatures

Studies of oxygen isotope fractionation between water in the hydration shells of dissolved ions and the remaining bulk water made at low temperatures by H. M. Feder and Henry Taube (1952) and J. R. O'Neil and A. H. Truesdell (1968) have been extended by Truesdell to 275°C for common salts. Dehydrated salts were added to water of known isotopic composition, and the solutions were equilibrated in a pressure vessel with CO_2 which was sampled for analysis. The water alone was studied similarly for comparison. Results on water coincide with CO_2-water fractionations calculated from Yan Bottinga (1968) and Bottinga and Harmon Craig (1969). Fractionations diminish with increasing temperature only for solutions of $MgCl_2$ and LiCl. Other salt solutions show complex behavior due to the temperature dependent formation of ion pairs of changing character.

The isotopic differences between CO_2 equilibrated with pure water and that equilibrated with 1 *m* salt solutions (that is, δCO_2 water$-\delta CO_2$ solution at the extreme temperatures studied (25°C and 275°C) are: NaCl (0.0, -1.0), KCl (-0.2, -2.8), LiCl (+0.3, +0.1), $MgCl_2$ (+1.1, +0.2), $CaCl_2$ (+0.4, -1.4), NaF (0.8 *m*)(0.0, +0.8), NH_4 Cl (0.55 *m*)(+0.1, +0.8).

These fractionations should be considered in the isotope study of geothermal brines and saline fluid inclusions. Because the quartz-water and calcite-water geothermometers were experimentally calibrated with solutions of 0.8 *m* NaF and 0.55 *m* NH_4Cl, respectively, they may require modification due to the effects reported here.

ADVANCES IN GEOCHRONOMETRY

Late Cenozoic marker ash beds of the Great Plains

Three ash beds of widely different ages compose what formerly was presumed to be a single ash marker bed of late Kansan age, the Pearlette Ash of the Great Plains. The oldest is represented at Borchers Ranch, Meade County, Kans., and has a fission-track age about 1.9 m.y., determined by C. W. Naeser from its zircon phenocrysts (C. W. Naeser and others, 1971). This and the other two ash beds, with ages respectively about

1.2 and 0.6 m.y., represent volcanic ash fallout from eruptions in the Yellowstone Park area that produced the three conspicuous ash flow members of the Yellowstone Tuff (G. A. Izett and others, 1971). Although very similar to each other, these ash beds may be distinguished by slight differences in the chemistry of their glass and in the chemistry and petrography of their phenocrysts, as determined by G. A. Izett and R. E. Wilcox.

Potassium-argon and rubidium-strontium measurements on P-207 muscovite

M. A. Lanphere and G. B. Dalrymple completed the final compilation of results on P-207, the USGS interlaboratory standard muscovite, which has been distributed to 55 laboratories in 15 countries. These countries are Australia, Brazil, Canada, England, France, Germany, Holland, Italy, Japan, Rumania, Union of South Africa, Union of Soviet Socialist Republics, Switzerland, United States, and Yugoslavia. Potassium-argon analyses of P-207 in 33 laboratories and rubidium-strontium analyses in 17 laboratories indicate that for this muscovite the average interlaboratory standard deviation is 1.2 percent for potassium-argon ages and 2.8 percent for rubidium-strontium ages, and the average intralaboratory standard deviation is 1.9 percent for potassium-argon ages and 3.0 percent for rubidium-strontium ages. The mean potassium-argon age of P-207 is 80.6±0.2 m.y. ($s_{\bar{x}}$); the mean rubidium-strontium age is 87.5±0.7 m.y. ($s_{\bar{x}}$). The differences between these ages may be due to common strontium of anomalous composition.

Extraneous radiogenic argon in hornblende, chlorite, and hydrothermal biotite

Fission-track ages by N. G. Banks and J. S. Stuckless and potassium-argon ages by N. G. Banks, H. R. Cornwall, M. L. Silberman, S. C. Creasey, and R. F. Marvin indicate that igneous activity associated with the Ray copper deposit, Arizona, began about 71 m.y. ago and terminated about 60 m.y. ago. An age of 60 m.y. for a Precambrian apatite annealed by heat from the ore fluids indicates that the deposit formed and then cooled below about 50°C soon after intrusion of the last igneous rock. Hydrothermal biotite from the deposit yields ages by the potassium-argon method that are older than the youngest host rocks, and hornblende and chlorite from the Laramide igneous rocks yield ages by the potassium-argon method that are anomalously older than potassium-argon ages of coexisting fresh or slightly chloritized biotite and fission-track ages of coexisting garnet, sphene, zircon, and apatite. Because the ages of the fresh igneous biotite are concordant with garnet, sphene, zircon, and apatite and because of restrictions imposed by petrologic and field data, the anomalous ages are not satisfactorily explained by argon loss from the biotite, xenocrystic contamination of the hornblende, and selective removal of potassium relative to argon from biotite during chloritization. All data are explained if the hornblende and chlorite incorporated extraneous radiogenic argon from deuteric fluids and if the hydrothermal biotite incorporated extraneous radiogenic argon from the ore fluids. The presumed source is Precambrian biotite that is known to have lost argon.

Ar^{40}/Ar^{39} technique of potassium-argon dating

In the Ar^{40}/Ar^{39} technique of potassium-argon dating, the sample is irradiated with fast neutrons to induce the reaction $K^{39}(n,p)Ar^{39}$. The age of the sample is then calculated from the Ar^{40}/Ar^{39} ratio. The method has two variations, the total-fusion technique in which the sample is totally fused after irradiation and all the argon released is analyzed in a single experiment and the age-spectrum technique in which the argon is released by stepwise heating. The applicability and limitations of both of the variations are being tested by G. B. Dalrymple and M. A. Lanphere (1971) and Lanphere and Dalrymple (1971).

Potassium-argon ages were determined by the Ar^{40}/Ar^{39} total fusion technique on 19 terrestrial samples whose conventional potassium-argon ages range from 3.4 m.y. to nearly 1,700 m.y. Sample materials include biotite, muscovite, sanidine, adularia, plagioclase, hornblende, actinolite, alunite, dacite, and basalt. For 18 samples there were no significant differences at the 95-percent confidence level between the potassium-argon ages obtained by these two techniques; for one sample the difference is 4.3 percent and is statistically significant. For the neutron doses used in these experiments ($\approx 4\times10^{18}$ nvt), it appears that corrections for interfering calcium- and potassium-derived argon isotopes can be made without significant loss of precision for samples with $K/Ca>1$ as young as about 0.5 m.y., and for samples with $K/Ca<1$ as young as about 10 m.y. For younger samples the combination of large atmospheric argon corrections and large corrections for calcium- and potassium-derived argon may make the precision of the Ar^{40}/Ar^{39} technique less than that of the conventional technique unless the irradiation parameters are adjusted to minimize these corrections.

Ar^{40}/Ar^{39} age spectra were determined for 10 terrestrial rock and mineral samples whose geologic history is known from independent evidence. The spectra for six mineral and whole rock samples, including biotite, feldspar, hornblende, muscovite, and granodiorite, that have experienced post-crystallization heating did not reveal the age of crystallization in any obvious way. Minima in the spectra, however, give reasonable maximum ages for reheating, and high-temperature maxima can be interpreted as minimum crystallization ages. High-temperature ages of microcline and albite that have not been reheated are approximately 10 percent younger than the known crystallization age. Apparently there are no domains in these feldspars that have retained radiogenic Ar^{40} quantitatively. Spectra from two diabase samples that contain significant quantities of excess argon might mistakenly be

interpreted as spectra from reheated samples and do not give the age of emplacement. The Ar^{40}/Ar^{39} age-spectrum technique may be a potentially valuable tool for the study of geologic areas with complex histories, but the interpretation of age spectra from terrestrial samples seems to be more difficult than suggested by some previous studies.

Uranium-series dating, Alaska and Tanzania

The richly fossiliferous interglacial beach deposit about 35 m above mean sea level at South Bight, Amchitka Island, Alaska, first described by H. A. Powers, R. R. Coats, and W. H. Nelson in 1960, contains sea-mammal bone fragments. On the basis of invertebrate collections, D. M. Hopkins in 1965 considered the age of the deposit to be most probably Anvilian, whereas R. C. Allison (Univ. Alaska) in 1971 considered the age to be Einahnuhtan.

Uranium-series dates were run on two samples of shell and one sample of sea-cow bone by B. J. Szabo. Though the Th^{230} and Pa^{231} dates of the two shell samples are not concordant (about 130,000±15,000 and 66,000±12,000 yr, respectively), the Th^{230} and Pa^{231} dates of the bone sample are considered concordant (about 135,000±12,000 and > 122,000 yr, respectively). The fossiliferous beds are directly overlain by unweathered till containing striated boulders of local material. The uranium-series dates, together with the presence of the overlying till, suggest that this deposit is probably Sangamon equivalent in age (L. M. Gard, Jr., and B. J. Szabo, 1971).

Four radiocarbon age determinations indicate that the Bootlegger Cove Clay in the Anchorage area, Alaska, was deposited about 14,000 yr ago. A new uranium-series age of 15,200±2,800 yr supports the radiocarbon age. In this age determination U^{234}/U^{238} activity ratios are measured and correction is made for extraneous Th^{230}. Previous uranium-series age determinations, ranging from 25,000 to 48,000 yr, did not employ these procedures and are seemingly invalid. The Bootlegger Cove Clay, which has been designated the type deposit for the Woronzofian transgression, is now interpreted to represent a marine transgression following the maximum development of the glaciation of Wisconsin age rather than an interstadial event of mid-Wisconsin age or an older glacial or interglacial event (H. R. Schmoll and others, 1971).

At the request of the British Museum (Natural History), London, dating of a bone sample from the Acheulian horizon in the archeological site at Isimila, Tanzania, has been completed. The results of Th^{230} and Pa^{231} dating indicate an age of 260,000+70,000 or 260,000-40,000 yr for the deposition. The fluorine and phosphate contents of other bones from the same horizon were found to be rather similar by K. P. Oakley (British Museum). Prof. F. C. Howell (Univ. California), who directed the excavation, finds the age consistent with artifactual evidence (F. C. Howell and others, 1972).

Uranium-thorium-lead systematics in Precambrian gneiss from Wyoming

Lead isotopic composition and concentration in six para-gneisses, a granitic gneiss, and two granites from the Granite Mountains area, Wyoming, were determined on whole-rock samples and seven associated feldspars by I. T. Nkomo and J. N. Rosholt (p. C169–C178). Uranium and thorium contents also were determined for the whole rocks and three of the feldspar samples. The Pb^{207}/Pb^{204} versus Pb^{206}/Pb^{204} data from the whole rocks define a line with a slope equivalent to a 2,950±120 m.y. isochron. A similar age of 2,925±80 m.y. obtained by the rubidium-strontium method on the same group of whole rocks may indicate the time of major metamorphism of these rocks (Z. E. Peterman and others, 1971). Lead-uranium and lead-thorium relations show marked discordance and cannot be used to calculate ages. In the whole-rock samples, uranium loss seems to have occurred during the Cenozoic.

ISOTOPE HYDROLOGY

The usefulness of isotopes in solving hydrologic problems increases as their characteristics and behavior become better understood. The techniques involve the use of naturally occurring isotopes or the artificial introduction of isotopes to obtain information on direction, rate, and volume of water flow. Various isotopes are used in geochemical studies investigating intermixing of waters and the chemical reactions that take place between them. The property of isotopes of being susceptible to quantitative measurement fosters their use in many different types of studies.

Analytical facilities and techniques

The USGS has added low-level carbon-14 measurement capability to its existing tritium detection and measurement facility. Liquid scintillation counting of benzene synthesized from the sample carbon is the method employed.

The normal procedures for preparing sulfate from natural waters for mass spectrometric analysis of sulfur isotope ratios fail when the sulfate content of the water is below about 100 mg/l. C. T. Rightmire and others developed a method to treat such waters. Acid chromatographic alumina is used to adsorb sulfate from samples of up to 5 l, and the sulfate is eluted with ammonium hydroxide. The recovery is high enough to eliminate the possibility of isotope fractionation during the extraction.

Carbon-isotope composition of soil CO_2

C. T. Rightmire and D. W. Fisher are conducting a study in central Florida to determine the relationship between the isotopic composition of soil CO_2 and that of the dissolved carbonate species in ground water. Soil-gas samples have been

collected and analyzed for CO_2 concentration and isotopic composition. This sampling was carried out under varying microclimatic and vegetative conditions to determine what effect differences in vegetation type have on the isotopic composition of the soil CO_2. A correlation was found between vegetation type and the carbon isotope composition of the soil CO_2. Plants using the Calvin photosynthetic cycle contain less carbon-13 and respire CO_2 of lower carbon-13 content than those using the C_4-dicarboxylic acid pathway of carbon fixation.

Tritium in precipitation and surface water

Monitoring of the tritium rainout in the United States continued. Changes made in the precipitation network included the discontinuation of the Denver, Colo., station and the addition of stations at Chicago, Ill., Hatteras, N.C., Panama Canal Zone, and Waco, Tex. The arithmetic mean weighted average tritium concentration for the 14 network stations within the United States decreased about 11.7 percent in 1969 compared with 1968 (12 network stations) and about 15 percent in 1970 compared with 1969. T. A. Wyerman extrapolated tritium concentrations from 1963 back through 1953 for the United States by correlation with the Ottawa, Canada, record. Results indicated an average tritium fallout during the period 1953-70 of 31 Ci per sq mi or a total of about 110 MCi for the entire United States for the 18 yr.

T. A. Wyerman continued work on the interpretation of tritium runoff for selected river basins in the river-tritium monitoring network, which now consists of 19 stations. Preliminary results suggested that, with the correct basin ground-water reservoir model, an estimate can be made of the minimum reservoir volume and the average residence time. Most network rivers displayed tritium concentrations exceeding that supplied by precipitation, thus demonstrating the lag effect of the ground-water component.

South Cascade Glacier tritium study

T. A. Wyerman and W. V. Tangborn continued a study of tritium in ice and runoff from the South Cascade Glacier in Washington. Results showed good correlation between the estimated ages of core samples and the age of winter precipitation in the area. The tritium concentration of streams flowing from the glacier may indicate the relative amounts of melt water and of current rainfall in each stream.

Behavior of oxygen isotopes in aqueous salt solutions

In experiments equilibrating trace quantities of CO_2 gas with salt solutions at various temperatures followed by isotopic analysis of the CO_2, A. H. Truesdell observed that the isotopic composition of the CO_2 depends on the temperature and the character and concentration of the salt. It can be shown that the overall isotopic fractionation is related to the molality of the ion, the number of water molecules per ion, and the fractionation per water molecule in each hydration shell.

The Frank-Wen model of ion-water interactions suggests that small cations have an inner hydration shell of tightly bound structured water molecules which in the present interpretation would concentrate O^{18} and that they have an outer hydration shell of dense but unstructured water molecules probably extending to several layers which may be expected to concentrate O^{16}. Anions other than F^- would have only the latter shell. The overall isotope fractionation would depend on the distribution and intensity of fractionation of water molecules in the different shells and these factors will be affected by temperature. Sodium chloride at low temperatures ($<50°C$) has an overall fractionation of 0.0. As the temperature is increased, the association of Na^+ and Cl^- increases, and at intermediate temperatures (50° to 150°C) predominantly solvent-separated ion pairs are found. This eliminates a portion of the outer hydration shell of the Na^+ ions and a portion of the hydration shell of the Cl^- ions. Thus the inner hydration shell of the Na^+ ions with its higher concentration of O^{18} dominates, and the overall effect is concentration of O^{18}. At higher temperatures, solvent-separated ion pairs are converted to contact ion pairs, the inner hydration shell of Na^+ is eliminated, and the overall fractionation becomes negative. NaF, KCl, NH_4Cl, and $CaCl_2$ solutions showed a similar pattern.

Saline ground water, Punjab, Pakistan

Saline ground water occurs in the irrigated doabs of the Punjab, Pakistan, and information concerning its origin is important to water-management planning in the region. William Back, R. N. Cherry, F. J. Pearson, Jr., and P. R. Seaber found that the carbon-14 contents of samples of fresh and saline ground water are consistent with regional ground-water flow patterns, and they concluded that the salt water is residual and is a result of conditions existing prior to irrigation.

Age of water in Arkansas hot springs

The age of water in an area of recharge to the springs in Hot Springs National Park is important to the National Park Service's management plans. F. J. Pearson, Jr., and M. S. Bedinger used carbon-14, the stable carbon and hydrogen isotopes, and water-mineral equilibrium calculations to determine that the water in the springs is about 5,000 yr old. As a result of this work, the part of the surrounding area which could be recharging the springs was delineated.

Stable sulfur isotopes

The isotopic composition of sulfate and sulfide in ground water may indicate the sources of these dissolved species. F. J.

Pearson, Jr., William Back, R. O. Rye, and C. T. Rightmire investigated the sulfate and sulfide in water from the Edwards aquifer in the San Antonio, Tex., region and the Floridan aquifer. In both aquifers, the isotopic composition of the sulfate suggests that it comes from solution of marine gypsum. In Florida, the sulfide results from reduction of the gypsum derived sulfate, while the sulfide in the Edwards aquifer is probably diffusing into the area of study rather than being formed in place.

SEDIMENTOLOGY

Sedimentology, the study of sediments and sedimentary rock, encompasses investigations of principles and processes of sedimentation and includes development of new techniques and methods of study. Sedimentology studies in the USGS are directed toward two ends: (1) Solution of water-resources problems, and (2) determination of the genesis of sediments and application of this knowledge to sedimentary rocks for more precise interpretation of their depositional environment. Many studies by the USGS involving sedimentology are directly applied to other topics such as marine, economic, and engineering geology, and to regional stratigraphic and structural studies; these are presented elsewhere in this volume under their appropriate headings.

Studies of fluvial sedimentation are directed toward the solution of water-resources problems involving water-sediment mixtures. Sediment is being considered more and more in terms of a pollutant. Inorganic and organic sediments transported by streams to sites where deposition takes place carry major quantities of sorbed toxic metals, pesticides, herbicides, and other organic constituents that accelerate the eutrophication of lakes and reservoirs. Knowledge of erosion processes, the movement of sediment in rivers and streams, and the deposition of sediment in stream channels and reservoirs is of great economic importance to the Nation.

TRANSPORT PROCESSES

Tracer studies of sediment-transport processes

R. E. Rathbun and C. F. Nordin, Jr., (1971) used fluorescent tracers to study the transport and dispersion of sand-size particles in sand-channel streams, one with a high-velocity, flat-bed condition and one with a low-velocity, dune-bed condition. The mean particle velocity for quartz tracer particles for the flat-bed condition was about 2 to 15 percent of the mean flow velocity, whereas the mean particle velocity for the dune-bed condition was approximately equal to the migration velocity of the dunes. Lateral dispersion of the tracer particles from the point source was greater for the dune-bed condition than for the flat-bed condition.

VARIABILITY OF SEDIMENT LOADS

Sediment loads in southern California

The relative importance of flood discharges in sediment transport in nearly ephemeral streams of southern California was clearly demonstrated in a study by C. G. Kroll of long-term sedimentation rates of the Santa Ana River at Santa Ana, Calif., and the Santa Maria River at Guadalupe, Calif.

During water years 1968–71, the mean daily suspended-sediment discharge of the Santa Ana River at Santa Ana was 7,200 tons, and the mean daily coarse-sediment discharge was 3,400 tons. Extrapolated over the 31 water years of streamflow record (1941–71), the mean daily values are 1,200 and 640 tons, respectively. In the Santa Maria River at Guadalupe, during water years 1969–71, the mean daily suspended-sediment discharge was 8,800 tons and the mean daily coarse-sediment discharge was 5,500 tons. Extrapolated over the 31 water years of adjusted streamflow record (1941–71), the mean daily values are 1,500 and 830 tons, respectively.

The estimated long-term coarse-sediment discharge of the Santa Ana River was 640 tons per day or 190,000 cu yd per yr and that of the Santa Maria River was 830 tons per day or 250,000 cu yd per yr. Only during floodflow is any significant quantity of sediment transported. In the Santa Ana and Santa Maria Rivers, 99.5 percent and 94 percent, respectively, of the coarse sediment was transported in 1 percent of the time.

Scour at bridges in Alaska

Several sets of scour-related measurements were made during 1971 at selected bridge sites in Alaska by V. W. Norman. The most significant data were obtained on August 11 at the upstream side of the bridge on Susitna River near Sunshine after a flood peak of 200,000 cfs. The bridge over the gravel and cobble bed is supported by four narrow pointed piers spaced 250 ft apart. A general scour of about 7 ft and a maximum point scour of 10 ft were measured between the second and fourth piers. The minimum bed elevation, which is in the left half of the channel, did not decrease during the peak but shifted 170 ft laterally. Local scour at the piers was minimal. A general fill of 1 to 2 ft occurred after the flooding had subsided.

VARIABILITY OF SEDIMENT YIELDS

Sediment yield produced by artificial rainfall

In a field study at Badger Wash, Colo., G. C. Lusby and R. F. Hadley measured the effects of artificial rainfall on arid upland watersheds. Rainfall at a rate of about 1.5 in. per hr was applied for 45 min to two small watersheds of about 5,000 sq ft each on 2 successive days. Soil in the first run was in a dry condition and in the second run was near field

capacity. The rainfall rates and amounts used are quite common in the Badger Wash area.

Of the rainfall applied, 24 percent occurred as runoff during the first run, and 44 percent occurred as runoff during the second run. Sediment concentrations increased from 35 tons per acre-ft of runoff in the first run to 42 tons per acre-ft in the second run. Consequently, the 20-percent increase in runoff was accompanied by a 20-percent increase in sediment concentration, both due to the antecedent moisture conditions. Soil-moisture measurements made before and after each run, in conjunction with rainfall and runoff measurements, showed that of 0.73 of an inch of water entering the soil during first run, about 33 percent had been lost by evapotranspiration 24 hr later.

Eleven hillslopes were surveyed in the watersheds before and after application of the rainfall to determine erosion rates. Each hillslope was divided into convex, straight, and concave segments. Analysis of variance of the survey data shows that maximum erosion occurs on the straight segments and least erosion on the concave segments.

Sediment yield related to measured watershed cover and geomorphic variables

Two multiple regression equations for sediment yield resulted from further analyses of data from eight small (0.09 to 1.18 sq mi) watersheds in the eroded, semiarid Cornfield Wash basin, a tributary of the upper Rio Puerco in northwestern New Mexico. L. M. Shown, J. R. Owen, and F. A. Branson found that 91 percent of the variance in annual sediment yield (SY) in acre-feet per square mile is explained by equation 1 with a standard error of estimate of 0.55, and 85 percent of the variance was explained by equation 2 with a standard error of estimate of 0.38 log unit.

$$SY=9.10-0.14\ VM+0.84\ ICL, \quad (1)$$

and

$$SY=4.94(ICL)^{3.21}\frac{R}{L}^{1.22}, \quad (2)$$

where VM= vegetation plus mulch cover, in percentage,
ICL= incised channel length, in miles, and
$\frac{R}{L}$= watershed relief-length ratio.

These three readily determined independent variables either directly or indirectly account for most of the factors that affect sediment yielded to reservoirs in the Cornfield Wash area. VM is related to infiltration rates of the soils, to watershed slope, and to $\frac{R}{L}$. Vegetation plus mulch cover is thus an inverse index of upland rill and sheet erosion. ICL serves as an index of channel erosion and also an index of the efficiency with which sediment is transported through the watershed.

Sediment characteristics and yields of Ohio streams

According to R. F. Flint, the nature of the parent materials of soils significantly influences the particle-size distribution of suspended sediment transported by streams. Suspended sediment in five streams which drain the unglaciated sandstone shale residual soil region of eastern Ohio had an average particle-size distribution of 40 percent clay, 49 percent silt, and 11 percent sand. In contrast, suspended sediment in four streams which drain the old glacial lakebed clay-soil region of northwestern Ohio had an average particle-size distribution of 84 percent clay, 14 percent silt, and 2 percent sand.

Sediment yield to Lake Tahoe, Nevada

P. A. Glancey (1971) reported that runoff during the 1970 water year from the five major streams in the Incline Village area was about 18,000 acre-ft. About three-fourths of the runoff was from Incline and Third Creeks. Sediment transported to Lake Tahoe by the major streams was estimated to be about 10,000 tons, of which about three-fourths was from Incline and Third Creeks. About 85 percent of the sediment was delivered to the lake during the snowmelt runoff period. The annual sediment load was estimated to be about 68 percent sand, 20 percent silt, and 12 percent clay. Sediment transported by streams during periods of runoff from rainfall generally contained greater percentages of silt and clay than that transported in runoff from snowmelt. Estimated annual sediment yields ranged from 50 to 650 tons per sq mi from undeveloped areas and 1,600 to 3,200 tons per sq mi from developed areas. Estimates suggest that about three-fourths of the 10,000 tons of sediment transported to Lake Tahoe during the year came from the developed areas and about one-fourth came from the undeveloped area. The resultant yield estimates suggest that the annual yield from the developed area was about 12 times that from the undeveloped area.

Sediment yields by streams of the upper Columbia River basin

L. M. Nelson estimated that annual suspended-sediment yields by streams in the upper Columbia River basin in Washington ranged from about 600 tons per sq mi from the Providence Coulee basin to less than 15 tons per sq mi from some of the more arid basins. Soils and land use are the major factors affecting sediment transport in the upper Columbia River basin.

Sediment yields of New Jersey coastal plain into Delaware estuary

L. J. Mansue reported that analyses of sediment data indicate that 1,000,000 tons per yr of sediment are transported by the Delaware River main stem and New Jersey coastal plain tributaries into the Delaware River estuary and

Delaware Bay. Approximately 20 percent of this amount is contributed by the coastal plain tributaries.

The suspended sediment transported was found to be related to areal variations in geology, physiography, and land use.

Sediment yields from highway construction

H. E. Reeder reported that a settling basin adjacent to a highway-construction site near Raleigh, N.C., trapped 126 cu yd of sediment from July 19, 1971, to September 16, 1971. During this period, the highway was being graded, and most of the 20-acre drainage area had no ground cover. Exposed land surfaces consisted of highway cuts, fills, and spoil areas. Total rainfall during the period was 9.8 in. The study was part of a continuing research program in cooperation with the North Carolina Highway Commission to explore methods of reducing sediment movement during highway construction.

GLACIOLOGY

Research by glaciologists of the USGS is directed toward the better understanding of snow, ice, and glaciers as water resources, as elements in the meteorologic and hydrologic environment of the high mountains, and as indicators of climatic change. Studies undertaken include the dynamics of ice flow, the relation of heat and mass exchanges at snow and ice surfaces, and the development and testing of new mass-balance measuring procedures.

Hydrology of glaciers

Austin Post and L. R. Mayo (1971) reported that several hundred glacier-dammed lakes in Alaska are large enough to produce potentially damaging floods below the glaciers. Thousands of smaller dammed lakes exist. Comparisons of periodic air photographs of the glacier-dammed lakes in Alaska indicated that new lakes form and old lakes disappear or change in size so rapidly that important lakes must be monitored annually or more frequently if predictions of outburst floods are to be valid.

R. M. Krimmel, W. V. Tangborn, and M. F. Meier (1972) studied the rates at which dye and salt tracers travel from the surface or margin to the terminus of South Cascade Glacier, Wash. Experiments were designed to determine water-percolation rates through the snowpack, firn, and ice parts of the glacier. Velocities in the snowpack were about 0.1 m per hr. Velocities from snow surface to terminus ranged from 6 to 27 m per hr, and velocities from moulins and marginal streams to terminus ranged from 266 to 2,450 m per hr. Results of three experiments to determine variations in velocity just above the equilibrium line indicated that snow depth and season are two rate-controlling factors. Velocities of free-flowing streams on the ice surface and at the margins suggested that there is open-conduit flow under the glacier.

Great piedmont glaciers of Alaska

Austin Post and George Plafker studied the nonsynchronous advances and retreats of Hubbard, Guyot, and Malaspina Glaciers, which are among the largest temperate glaciers in the world. Two major advances (as much as 60 km) and retreats of Hubbard and Guyot Glaciers have occurred in the past 1,500 yr; at the present time, both terminate in fiords far back in the mountains. Moraine position and other evidence indicate that the Malaspina Glacier also has made large-scale retreats and advances. The Hubbard Glacier is advancing, the Guyot Glacier is retreating phenomenally, and the Malaspina Glacier is near its greatest known advance. The anomalous behavior of these glaciers does not seem to be related to differences in snow accumulation or snowline altitudes; rather, it appears to be realted to the varying depths of the tidewater in which they terminate. Advances occur when the glaciers build and push forward terminal moraine bars which inhibit iceberg discharge. Retreats occur when the glaciers melt back from shoals and calve into deep water. This mechanism may explain the large nonsynchronous advances and retreats of other tidal glaciers throughout the world.

The Malaspina Glacier exhibits a complex pattern of folded medial moraines. These moraines appear to originate at the narrow (5-km-wide) throat where the Seward Glacier accumulation area (2,000 km^2) debouches into the ablation area of Malaspina Glacier (1,500 km^2). R. M. Krimmel, Austin Post, and Donald Richardson measured the surface velocity field of the ice at this throat, and gravity readings were taken to estimate the depth of ice in this measured section. Surface velocities were about 4 m per day, somewhat less than the 5.8 m per day determined from the movement (during a 2-yr period) of a marker set by George Plafker in 1969. Gravity anomalies indicated a maximum ice depth of about 500 m. Annual ice discharge through the throat was calculated to be about 2.6×10^9 m^3. If the glacier were in a steady state, the average ice balance in the drainage area would be about 1.3 m annually.

Current behavior of Nisqually Glacier, Washington

Nisqually Glacier responds to slight changes in climate. Annual measurements of surface altitude and ice movement at three profiles on Nisqually Glacier have documented a kinematic ice wave resulting from an increase in thickness at the upper profile from 1945–51. As the wave progressed down glacier, there was an increase of 36 m in mean altitude at the middle profile (1948–63) and 39 m at the lower profile (1954–65). In recent years, measurements by Donald Richardson revealed the complete passage of the ice wave, with decreasing altitudes observed at the lower profile since 1965. Ice advance at the glacier terminus had ceased by 1968, and a gradual recession has resumed. Since 1968, ice has again been building up at the upper profile; the present buildup is

producing another kinematic wave that may eventually cause the glacier to advance again.

Surges of Black Rapids Glacier, Alaska

Because Black Rapids Glacier has surged into the Delta River valley at least three times within the last 350 yr, it may pose a potential hazard to the proposed trans-Alaska oil pipeline. Chester Zenone and L. R. Mayo collected surface-altitude data on Black Rapids Glacier in 1970 in order to construct the glacier's current surface profile. Comparison of that profile with one drawn from earlier (1950) topographic maps shows a significant change over the 21-yr period. The surface of the glacier's accumulation zone is nearly 100 m higher along some sections of the 1970 profile than it was in 1950. In 1971, the profile was resurveyed and the measurements indicated that buildup for the next surge is proceeding.

PALEONTOLOGY

Research by paleontologists of the USGS involves biostratigraphic, paleoecologic, taxonomic, and phylogenetic studies of a wide variety of plant and animal groups. The results of this research are applied to specific geologic problems related to the USGS program of mapping geology, investigating resources, and providing a biostratigraphic framework for synthesis of the geologic history of North America and the surrounding oceans. Some of the significant results of paleontological research attained during the past year, many of them as yet unpublished, are summarized in this section by major geologic age and area. Many additional studies are carried out by USGS paleontologists in cooperation with other members of the Survey. The results of these investigations are reported under the section "Geological, Geophysical, and Mineral-Resource Studies," p. A16.

PALEOZOIC OF THE EASTERN STATES

Devonian paleobiogeography

Analysis by W. A. Oliver, Jr. (1971) of the world distribution of rugose coral genera that occur in the eastern half of North America (east of an axis running from central Hudson Bay to the Gulf of California) in rocks of latest Silurian and Devonian age helps to delineate paleobiological provinces of this time period and to outline their history. If Eastern North America (ENA) endemic genera are defined as those known only from ENA, northern South America, northwestern Africa, and Spain(?), then a stage-by-stage history of the development and later disappearance of an ENA province can be outlined by the percentage of endemics in each stage: Pridoli (latest Silurian), 15 percent Gedinnian, 57 percent; Siegenian, no data; Emsian, 90 percent; Eifelian, 62 percent; Givetian, 45 percent; Frasnian (early Late Devonian), 0 percent.

The outlined distribution patterns support a Devonian geographic model similar to the best-fit reassembly of North and South America, Africa, and Europe of E. C. Bullard and others (1965). To an unknown extent the Pridoli to Emsian increase in endemism paralleled the development of the Old Red Continent between what is now the Appalachian belt and Europe while western and eastern North America were separated by the Transcontinental arch. Decrease in endemism in Givetian time is at least partly due to the movement of Old World coral genera from a western sea in the Dakotas across the arch into the ENA Michigan basin; this movement may have begun in the Eifelian, but there is no available evidence of the timing. The decrease culminated in the Frasnian with the joining of eastern and western seaways across the arch in several areas.

Cambrian and Ordovician trilobites from east-central New York State

Trilobites from the lower part of the Whitehall Formation of Rodgers (1937) near Whitehall, N.Y., are assignable to the *Saukia* Zone, and those from the upper part, to the *Missisquoia* Zone, according to M. E. Taylor. The trilobite faunas document the occurrence of the Cambrian-Ordovician boundary within the formation as had previously been inferred by D. W. Fisher (1969). The *Saukia* Zone fauna exhibits a high degree of similarity with coeval faunas from the central Appalachians (Conococheague Limestone), southeastern Missouri (Eminence Dolomite), south-central Oklahoma (Signal Mountain Limestone), central Texas (Wilberns Formation), and east-central Great Basin (Whipple Cave Formation of Kellogg (1963), and Notch Peak Limestone). In contrast, the Whitehall fauna exhibits few taxa in common with the partly coeval "*Hungaia magnifica* fauna" which has been reported from western Newfoundland (Cow Head Group), Levis in Quebec (boulders in Levis Conglomerate), northeastern Vermont (Gorge Formation of Schuchert (1933)), and the central Appalachians (Frederick Limestone). Faunal differences between the two main regions are attributed to environmental differences between shallow-shelf (Whitehall and related areas) and basinal ("*Hungaia magnifica* fauna") sites of deposition during Late Cambrian (Trempealeauan) time.

Early Ordovician oceanic waters indicated as source of epicontinental faunas

Study of Early Ordovician brachiopods from eugeosynclinal rocks bordering the Atlantic Ocean suggests to R. B. Neuman (1972) that the bottom of the ocean surrounding Early Ordovician oceanic islands supported a rich and diversified fauna from which many stocks of the epicontinental seas were probably derived. Such islands are represented in the northern Appalachians by small widely separated outcrops of dominantly volcanic rocks in Maine, New Brunswick, and New-

foundland and in the British Isles by detrital rocks on the flanks of the Irish Sea uplift. Brachiopods in these rocks include (1) many genera that are new and are probably indigenous, (2) genera known elsewhere from different faunal provinces of the Early Ordovician but not hitherto known to occur together, and (3) genera that are premonitory of the later Ordovician. Selective and episodic migration of stocks from islands to continental margins together with in situ evolution of stocks that thrived in their special environments determined the composition of the well-differentiated Early and early Middle Ordovician provincial faunas.

Bryozoa from the Millersburg Member of the Lexington Limestone (Ordovician) of central Kentucky

Bryozoans collected from the reference section of the Millersburg Member in Winchester quadrangle, Clark County, were identified by O. L. Karklins as representing zone B of the preliminary bryozoan zonation of the Lexington Limestone in central Kentucky (E. R. Cressman and O. L. Karklins, 1970). The bulk of this faunule consists of *Constellaria teres* Ulrich and Bassler, *Peronopora milleri* Nickles, and species of *Eridotrypa*, *Hallopora*, *Homotrypa*, *Heterotrypa*, and *Escharopora*. These taxa belong to an assemblage transitional between late Middle and early Late Ordovician bryozoans. However, the morphological aspect of the greater part of the taxa in this faunule suggests an early Late Ordovician age for the Millersburg Member at its reference section. Large numbers of silicified bryozoans obtained by John Pojeta, Jr., from the Millersburg Member show several colony forms that are almost complete. The presence of large robust zoaria with subcylindrical branches together with small bushy zoaria with delicate branching patterns in one collection from the basal part of the section seems to indicate a local environment in which little sorting occurred.

PALEOZOIC OF THE WESTERN STATES

Molluscan diversity in Amsden Formation

A study of the gastropods, cephalopods, and trilobites of the Amsden Formation of Wyoming was completed by Mackenzie Gordon, Jr., and E. L. Yochelson. A high degree of diversity can be observed among the gastropods with as many as 48 species probably present, belonging in 28 genera distributed among 20 families and 11 superfamilies. They approach the brachiopods in taxonomic diversity although the brachiopods are 20 times more numerous. The Bellerophontacea account for one-half and the Euomphalacea one-sixth of the total gastropod fauna. Cephalopods are rare—only one specimen of *Cravenoceratoides* is identifiable as to genus. Trilobites all are referable to the genus *Paladin*. Although the genera are of little use in delimiting the Mississippian-Pennsylvanian boundary, different species are present above and below this boundary.

Ostracodes from the Amsden Formation

P. S. Morey (1935) described and illustrated the ostracodes from the Amsden Formation of Wyoming. Subsequently, many of his species were identified from Mississippian (late Chesterian) rocks in the midcontinent region. In a revision of Amsden ostracode assemblages, I. G. Sohn concludes that the recorded occurrences of Morey's species outside of Wyoming are based on misidentifications. The ostracode species of the Horseshoe Shale Member of the Amsden Formation of Wyoming are interpreted as representing an endemic assemblage. Other species of all genera found in the Horseshoe Shale Member, however, are found elsewhere in rocks of late Paleozoic age. Species of some, such as *Balantoides* Morey, 1935, *Clyptopleurites* Coryell and Johnson, 1939, and *Tetratylus* Cooper, 1941, are restricted to rocks of pre-Pennsylvanian age.

Ostracodes from Lower Devonian of Alaska and Yukon Territory

A varied silicified ostracode fauna from the McCann Hill Chert in Alaska and the Michelle and Prongs Creek Formations of Yukon Territory has been studied by J. M. Berdan (USGS) and M. J. Copeland (Geol. Survey Canada). More than 70 ostracode taxa are described and illustrated, including six new genera and 32 new species. This fauna extends from the Alaska-Yukon international boundary near lat 65° N. for more than 200 mi to the northeast and may assist in correlations in this area. Of the more than 40 ostracode genera present, hollinids and beyrichiids are the most distinctive. The hollinids are most closely related to genera from the Eifelian part of the Jeffersonville Limestone of Indiana and Kentucky, whereas the beyrichiids are related to genera from Siegenian and older formations of Appalachian North America and northern Europe. Megafossils and conodonts described by other workers from the same collections from which the ostracodes came have been determined as Emsian in age; the ostracode assemblage, however, is unlike any described Emsian fauna and apparently represents a new and distinct faunal province.

Biostratigraphy of Carboniferous of northern Alaska

Depositional patterns and facies are major controlling factors of Carboniferous biostratigraphy in Arctic Alaska. Marine onlap was dominant in the Early Mississippian, the most continuous deposition being in the central part of the Brooks Range. On both the northeast and west, progressively younger Mississippian beds lie on older Paleozoic terrane. Correlations with other parts of the American Arctic indicate that this northward and eastward onlap was a general pattern in the Carboniferous; Eurasian and cosmopolitan faunal elements became more prominent after middle Mississippian time.

Oldest marine rocks are in the Shainin Lake area, central

Brooks Range, where basal Mississippian nearshore clastic rocks succeed Upper Devonian nonmarine strata. By Meramecian time the seas had spread across northern Alaska, except for the northernmost areas (Barrow-Sadlerochit Mountains trend). Carbonate deposition continued into the Pennsylvanian and Early Permian near the center of the eastern Brooks Range, but there was uplift in the Sadlerochit-Shublik Mountains area after Middle Pennsylvanian time.

Megafossil zonation proposed by J. T. Dutro, Jr., and A. K. Armstrong (1970) is based mainly on ranges and occurrences of lithostrotionoid corals, brachiopods, bryozoans, echinoderms, and mollusks. Twelve assemblage zones are named and described.

Pennsylvanian megafossil zonation is not as clearly defined as that for the Mississippian, but two main assemblages occur: a Morrowan bryozoan-echinoderm assemblage and an Atokan *Corwenia-Lithostrotionella* assemblage. Larger fossils other than corals are rare in Pennsylvanian strata.

The megafossil succession is consistent with that developed for the Foraminifera by B. L. Mamet, and only minor difficulties arise when correlations are attempted with other parts of the world.

Utility of conodonts in Pioneer Mountains, Idaho

Conodont samples from previously undated stratigraphic units throughout the Pioneer Mountains of central Idaho have been processed and determined by C. A. Sandberg. To date, samples furnished by Claus Axelsen (Oregon State Univ.), R. A. Paull (Univ. Wisconsin), and B. A. Skipp (USGS), have yielded faunas of Early Mississippian (Kinderhookian), Late Devonian (both Famennian and Frasnian), and Middle or Early Devonian age. Megafossils are little known from the thick Paleozoic argillites, quartzites, and conglomerates of the Pioneer Mountains, and hence many parts of the sequence have not been dated nor correctly correlated. The finding of several different conodont faunas in relatively few samples of thin interbedded limestones suggests that conodonts are abundant in this area and will prove extremely useful in unraveling the complex stratigraphy and structure.

New Devonian conodont zone in Nevada and Germany

Detailed study by C. A. Sandberg has revealed the presence of a previously unrecognized early Famennian conodont fauna at Bactrian Mountain, Nev. This new fauna occurs between the upper *Palmatolepis crepida* and *P. rhomboidea* zones within the West Range Limestone in a section measured by C. A. Sandberg and F. G. Poole (1970). During a joint study with Prof. Willi Ziegler (Phillipps Univ., Marburg) the same fauna was found in samples from the Kellerwald, Federal Republic of Germany. Because of the wide distribution of this distinctive assemblage, a new conodont zone is being proposed by Sandberg and Ziegler to be inserted within the standard Late Devonian conodont zonation (Ziegler, 1962).

Paleoentomological novelties found by paleobotanists

Incidental to their fossil plant collecting in Pennsylvanian rocks of New Mexico, C. B. Read and S. H. Mamay have found well-preserved fossil insects, recently described by F. M. Carpenter (1970). The specimens demonstrate body parts and wing markings and are treated as three new genera. Two of these represent the first reported New World occurrences of their respective families, and their type species are named after the collectors (*Sandiella readi*, family Eugereonidae; *Madera mamayi*, family Lycoceridae); the third new genus, *Pseudobiella fasciata*, represents the family Perobiellidae, previously recorded only from the Lower Permian of Kansas. One unnamed specimen, a roach, is of special interest as it shows the hind wings which are scarcely known among Paleozoic roaches.

MESOZOIC OF THE UNITED STATES

Geographic distribution of fossils extended into Canada

Collections of Cretaceous mollusks from Alberta, Saskatchewan, and Manitoba submitted to W. A. Cobban for identification by Prof. W. G. E. Caldwell (Univ. Saskatchewan, Saskatoon), revealed the occurrences of two well-known species much farther north than known previously. The geographic range of the Campanian ammonite, *Baculites perplexus* Cobban, formerly known from the San Juan Basin of northwestern New Mexico to central Montana, can now be extended northward to Delmas, Saskatchewan, 270 mi north of the international boundary. *Ostrea beloiti* Logan, a late Cenomanian species found at many localities from the San Juan Basin to the Black Hills, is now known from collections made at several localities in the Ashville Formation of Manitoba 140 to 260 mi north of the international boundary.

Reappraisal of the "oldest certain angiosperms"

The age of the oldest flowering plants is a continuing question in paleobotany. Roots and stems of palms recently were described from the Arapien Shale (Jurassic) in central Utah as the first certain pre-Cretaceous angiosperms. Through the courtesy of W. D. Tidwell (Brigham Young Univ.), the original localities were visited and additional material was collected by R. A. Scott, P. L. Williams, and L. C. Craig (all of USGS), E. S. Barghoorn (Harvard Univ.), L. J. Hickey (Smithsonian Inst.), and H. D. MacGinitie (Univ. California, Berkeley). Field and laboratory study shows that both the palm roots and palm wood originated in nearby Tertiary rocks. Consequently, these fossil palms from Utah cannot be regarded as authentic pre-Cretaceous flowering plants.

Jurassic paleobiogeography of Alaska

By comparisons of faunal, stratigraphic, and lithologic

evidence from various parts of Alaska, R. W. Imlay and R. L. Detterman (1972) have completed a study which demonstrates that throughout Jurassic time, seas were marginal and probably never covered large areas in central and west-central Alaska. Judging by the distribution of Jurassic rocks and the contained fossils that are characteristic of the various stages, the seas were most extensive during the Sinemurian, Bajocian, and late Oxfordian to middle Tithonian; they were much restricted during the Hettangian, Bathonian, and late Tithonian; and they were absent during the late Callovian.

CENOZOIC OF THE UNITED STATES

Oligocene correlations in California

Biostratigraphic study of marine invertebrates from the lower part of the type Temblor Formation, California Coast Ranges, by W. O. Addicott (1972) indicates that this fauna is distinct from stratigraphically higher assemblages of the lower Miocene "Vaqueros Stage," to which it had been formerly assigned, and that it is underlain by a molluscan assemblage referable to the middle Oligocene Refugian Stage. This fauna is particularly significant because it constitutes a previously unrecognized time-stratigraphic unit in the sequence of California provincial megainvertebrate stages; it also provides a direct correlation with the type section of the Zemorrian Stage of the provincial microfaunal sequence. The 50 mollusks comprising this fauna have received systematic study; collectively they are indicative of a shallow-water subtropical marine environment.

Utility of sea lions and walruses in Cenozoic correlations

Sea lions and walruses are a late Cenozoic group largely confined to Pacific Basin areas. Recent studies by C. A. Repenning have led to the delineating of two new species and to refinements in the known morphologic distinctiveness, taxonomic status, geologic and geographic range, and synonymies of several previously described fossil forms. The result has been a significant increase in the usefulness of the walruses in the correlation of deposits from Mexico to Oregon. Implications of lesser reliability are apparent in correlations of seal assemblages with Japan and the Australia–New Zealand region.

From approximately 12 to 10 m.y. ago the Pacific coast seal assemblages were dominated by a small primitive fur seal and a large walrus, very much like a sea lion. The tuskless ancestor of the living walrus, a second walrus of very large size but very aberrant in its specializations, and a primitive species of the living fur seal genus *Arctocephalus* were present along the Pacific coast from Mexico at least as far north as Oregon from approximately 9 to 5 m.y. ago. During the latter part of this period it appears that the ancestor to the living walrus dispersed through the Arctic Ocean into the Atlantic together with some mollusks of Pacific origin which today are still a major factor in the diet of the walrus. About the same time the fur seals dispersed southward to the South Pacific where they spread through the seas surrounding Antarctica, and sea lions evolved from these immigrants. Fur seals never entered the Atlantic, suggesting that the Central American seaway was effectively closed at this time.

The earliest sea lion is known from deposits in New Zealand which are apparently 4 to 5 m.y. old as based on current correlations of marine invertebrates. This sea lion is believed to belong in a living genus. In deposits along the Pacific coast of North America the earliest seal remains that could be sea lion are about 3 m.y. old, and living genera are not recognizable in fossils that are older than about 2 m.y. A similar situation appears to have existed in Japan although the fossil record there is very poor. At present it is not known whether the sea lion evolved from the fur seals separately in both the North and South Pacific, but later in the north, or whether their earlier appearance in the south indicates that evolution occurred completely in the south and they dispersed northward 3 to 2 m.y. ago.

In the North Pacific there is no record of the lineage leading to the modern walrus during the period from about 7 m.y. ago to the late Pleistocene. In contrast, the North Atlantic abounded with various types of walruses during this period, and it is suggested that the lineage became extinct in the Pacific and was reintroduced in the form of the modern walrus in late Pleistocene time.

Steller's sea cow in Pleistocene deposits on Amchitka

A partial skeleton of Steller's sea cow, *Hydrodamalis gigas* (Zimmermann), was collected by L. M. Gard, Jr., and F. C. Whitmore, Jr., (Gard and others, 1972) from a beach deposit of Pleistocene age, 35 m above present sea level on Amchitka Island, Aleutian Islands. This discovery is the first Steller's sea cow in place in beds of Pleistocene age.

Hydrodamalis, the only Arctic sea cow, was discovered alive in 1741 by the German naturalist G. W. Steller on what is now known as Bering Island in the Komandorskiye Group. The animals, which fed on kelp in shallow water, were huge (30 ft long and 3½ tons in weight) and sluggish. By 1768 they had been exterminated by hunters who killed them for fresh meat for whaling vessels. They have never been sighted alive anywhere else.

Fossil remains of the genus are equally scarce. A skull was dredged from Monterey Bay, Calif., in 1960, and two specimens have been discovered in the Pliocene of California.

The Amchitka specimen is immature but is as large as the average adult of the Bering Island fauna, as determined from measurements of bones found on the beach there. It is possible that the Bering Island sea cows represented a population that was approaching extinction under marginal ecologic conditions and that Pleistocene members of the genus were larger.

The deposit in which the Amchitka specimen was found was laid down under interglacial conditions in Sangamon time. It is

unique in the central Aleutian chain. The presence of *Hydrodamalis* on Amchitka suggests that the sea cow lived around other Aleutian islands in Pleistocene time but that few deposits containing their bones have survived.

Paleocene-Eocene boundary criteria discrepancies in Wind River Basin

The Paleocene-Eocene boundary in the Wind River Basin of Wyoming, as recognized on the basis of heavy mineral content, does not coincide with that boundary as placed on palynological evidence according to R. H. Tschudy. Pollen and spores derived from samples provided by G. H. Horn and N. M. Denson from beds on both sides of the boundary picked on the basis of heavy mineral content show no easily recognizable palynologic change. The geologic event that introduced a different suite of heavy minerals into the rocks preceded the floral change that marks the passage from the Paleocene to the Eocene in this region.

Palynological change in Gasbuggy cores

A Paleocene-Cretaceous transition is demonstrable at a depth of about 3,640 ft on the basis of palynological contents of 15 samples from the uppermost 12 Gasbuggy cores (3,436–3,844 ft), from the San Juan Basin of northern New Mexico. Critical taxa involved are *Proteacitides* spp., *Aquilapollenites* spp., *Tricolpites reticulatus*, and *Liliacidites complexus*. These palynomorphs have been shown by USGS personnel and by other workers (R. Y. Anderson, 1960; H. A. Leffingwell, 1971) to indicate Cretaceous age; in the Gasbuggy cores, they persist in the interval from 3,640 to 3,844 ft, the deepest sample examined as yet.

Paleocene and Eocene climates

Physiognomic analyses of Paleocene and Eocene leaf-floras from the Gulf Coast Mississippi embayment region by J. A. Wolfe give a definite indication that—as in the Pacific Northwest and Alaska—there were pronounced climatic fluctuations. The Midway and late Wilcox floras are characterized by a dominance of large leaves and a high percentage of entire-margined leaves indicating tropical rain forest. The intervening early Wilcox floras indicate a considerably cooler, although moist, climate. The earliest Claiborne floras are indicative of a somewhat cooler climate than the bulk of the Claiborne floras; all the Claiborne floras, however, indicate a definite precipitational deficit. The small, poorly known floras of the early Jackson indicate a cool, dry climate, and the late Jackson floras indicate a return to a dry, tropical climate.

Paleocene in outcrop in North Carolina

Paleocene rocks have long been known at the outcrop in New Jersey and more recently their presence has been noted in Maryland. D. J. P. Swift and S. D. Heron (1969) have extended the Black Mingo Formation of South Carolina into North Carolina at a single outcrop on the Neuse River at West Landing. Strata referred to the Black Mingo in South Carolina are, at least in part, of Paleocene age. Recently, W. C. Blow made a collection of brachiopods and oysters from a glauconitic sandy matrix on the spoil bank of newly deepened Mosley Creek on the Lenoir-Craven County line in North Carolina. Subsequently, they were recognized by Druid Wilson as *Oleneothyris harlani* (Morton) and a pycnodont oyster sometimes called "*Gryphaea vesicularis* (Lamarck)," which is probably a form of *Pycnodonte dissimilaris* (Weller). Both are common fossils in a zone of the Paleocene of New Jersey and Maryland. Later fieldwork established that the outcrop of the formation is about 2 ft above water level and extends along the creek for about a mile. It is overlain disconformably in places by about a foot of Castle Hayne Limestone (Eocene) of typical lithology. It appears to be an extension of the subsurface Beaufort Formation (Paleocene) of P. M. Brown (1959). The microfossils are comparable. The outcrop strikingly upholds a structural trend discovered by Brown (Brown and others, 1972) in his study of the subsurface in his definitive work on Coastal Plain subsurface geology.

Pollen analyses of peat and clay from coastal Maryland

Ten samples of peat and clay collected during a hydrologic study in northeastern Worcester County, and three samples collected 60 mi inland near Salisbury, Md., have been analyzed palynologically. According to J. M. Weigle the results point to an age younger than has been assumed for some of the deposits.

The uppermost part (at least 20 ft thick) of the dark silt, clay, and fine sand, beneath what has been considered to be the base of the Pleistocene deposits, is also Pleistocene in age. Previously these dark, fine-grained materials have been assumed to be Miocene or possibly Pliocene in age.

OTHER PALEONTOLOGICAL STUDIES

Origin of micrinite in coal

An unusual occurrence of micrinite in a West Virginia coal, originally studied by Reinhardt Thiessen, has been reinterpreted by J. M. Schopf (1972a). Micrinite represents organic matter more highly altered than most of the woody plant remains with which it is associated in this and other coal beds. It has many properties similar to fusain (mineral charcoal) but is more finely dispersed. The physical condition of the material is important in determining its origin. If micrinite and fusain represent similar modes of primary alteration of a part of the fossil plant residues in coal, the forest-fire origin of fusain would appear unlikely. Both fusain and micrinite probably are differentiated early in the peat stage by chemical processes that reacted differently on the other organic

components of coal. All, however, originated in a wet environment.

Origin of distinctive southern floras

According to J. M. Schopf (1970, 1972b), distinctive and different groups of fossil plants occur in both Permian and Triassic deposits in the Gondwana areas of Australia, India, central and southern Africa, eastern and southern South America, and Antarctica. In agreement with fossil plant occurrences, plate tectonics implies that all these areas were juxtaposed during the Permian and Triassic. During most of this time plant fossils suggest a nearly complete isolation of the northern and southern floras. The ancestors of the Permian glossopterids and conifers however, probably migrated southward in Middle Pennsylvanian time; the ancestors of Triassic *Dicroidium* and other corystosperas probably migrated to the Gondwana region near the end of Late Permian time. Both the glossopterids and the corystosperms were amazingly successful, in turn, in populating the southern terrane. It is not clear, however, how the corystosperms were able to replace, almost completely, the earlier, dominant glossopterid assemblage; also, the means of migration from the north is undetermined. If answers to these problems can be suggested, it will aid in correlation of southern continental deposits and contribute a better understanding of continent displacement.

GEOMORPHOLOGY

Ancient stream diversions clarify origin of uranium deposits in south Texas

D. H. Eargle has found evidence in south Texas that radical changes in river courses involving the Rio Grande system have occurred since early Pliocene time. Gravels containing volcanic pebbles and boulders corresponding to rock types found in the Big Bend region of west Texas have been known for some years in areas far to the north of the lower Rio Grande basin. These include pebbles of riebeckite rhyolite that can have originated in the United States only in the volcanic region of the Big Bend and Davis Mountains. Some of the rocks may have originated in Mexico, but the rocks of Mexico are less well known than are those of Texas.

Widely distributed pebbles of silicified fossiliferous limestone containing fusulinids have been identified by D. A. Meyers as of Permian Word age. They are presumed to have originated in the Trans-Pecos Glass Mountains just west of the Marathon basin, as the only outcrops of these rocks in Texas are in these mountains. The pebbles are in basal gravels of the Pliocene Goliad Sand and in Pleistocene terraces of the Nueces River, the next large river system north of the present Rio Grande.

The extensive distribution of these pebbles in south Texas as well as geomorphic evidence suggests that important drainage changes have formed the present course of the Rio Grande. Apparently, large areas of Trans-Pecos, Texas, including perhaps the Pecos basin itself, were once drained by an ancestral Nueces River system, but the upper tributaries of that system were pirated by a tributary of the Rio Salado in Mexico to form the present Rio Grande. The Rio Salado, a large river system south of the Rio Grande, joins the present Rio Grande in Falcon Reservoir about 150 mi above the mouth of the Rio Grande.

The ancient stream channels that originated in west Texas overlie uranium deposits recently discovered in truncated porous sands in south Texas. The channels may have been the agents that brought the uranium in weak solution to its places of deposition, chiefly in faulted areas where precipitants such as natural gas and hydrogen sulfide were present.

Flood damage to watersheds affects land use

Timely measurements of terrain by H. E. Malde in a semiarid landscape near Santa Fe, N. Mex., have documented sudden changes that were caused by recent floods in several arroyos. The changes occurred during successive rainstorms in late July 1971 after a period of prolonged drought.

In one arroyo, which was flooded by a storm that severely contaminated the water supply of Santa Fe, changes in the terrain were measured by comparing duplicate photographs that were made by the methods of terrestrial photogrammetry before and after the flood. Flooding beyond the arroyo banks reached a depth of 3 ft and spread across a width of 700 ft., but the main effect was the deposition of masses of perishable flotsam.

The flooding of another arroyo by a subsequent storm destroyed the water supply of Los Cerrillos southwest of Santa Fe. Changes in the upper reach of this arroyo, which in one place amounted to more than 34 ft of headward erosion in half an hour, were documented by repeated photographs and were measured by engineering surveys before and after the flood. From these measurements and photographs, M. S. Petersen calculates that the discharge was 4,000 cfs.

At still another arroyo where the discharge is routinely measured by the Water Resources Division, changes caused by runoff during these successive rainstorms were further documented. These observations made use of the techniques of terrestrial photogrammetry and engineering surveys, as at the other arroyos, and they were supplemented by repeated planetable mapping and by measurement of erosion at steel pins that had been driven into the arroyo walls. Data obtained by A. G. Scott show that the respective discharges were 211 and 649 cfs. This runoff caused 11 ft of headward erosion.

By documenting such changes in terrain, the probable consequences of future rainstorms at Santa Fe can be predicted. Such knowledge is of value in reaching decisions on designs for land use.

The measurements and the photographic records have been assembled as documentary material for the Vigil Network—a file of detailed data on geomorphology and hydrology that is

maintained by the USGS.

Experimental application of factor analysis to geomorphic classification

A 10×13 km rectangular test area contained in the Fort Belvoir (Va.-Md.) 7½-minute quadrangle map was selected for a quantitative geomorphic analysis experiment by R. A. Cadigan. For data compiling purposes, the area was divided into 130 data cells, each 1-km square. Data for nine terrain parameters were obtained manually for each cell. The nine parameters used are (1) the number of 100-m squares in each of the data cells that contain shorelines, beaches, swamps, and stream and river banks, (2) the number of contour lines (total) that cross the four boundaries of each data cell, (3) altitude in feet of the highest point in each data cell, (4) the altitude of the lowest point in each data cell, (5) the number of 100-m squares in each data cell whose surface is all water, (6) the number of 100-m squares in each data cell occupied by interfluve areas with slope of less than 6 percent, (7) the number of 100-m squares in each data cell that contain terrain with 6 percent or steeper slope, (8) the number of 100-m squares in each data cell occupying flat (less than 6 percent slope) lowland, valley bottoms, flood plains, and tidal land, and (9) the natural log of the relief in each data cell.

The nine parameters for each of the 130 1-km-square areas produced a 130-row, nine-variable data matrix. Linear correlations were then computed between all possible pairs of variables which produced a 9×9 correlation matrix. This matrix was used as a basis for *R*-mode factor analysis.

Only two factors were found to be significant. The numerical loadings of variables in the rotated factor matrix led to the interpretation that, in terms of geologic process and in order of importance, the two factors were (1) uplift and dissection and (2) abstraction and subsidence. The loadings for the nine variables relative to the two factor axes represent nine coefficients in each of two equations; each of the equations measures the effects of one of the two geologic factors.

The nine parameter values for each data cell were entered into the equations to give a factor score for the 130 1-km-square data cells for each of the two factors. Isopleths were drawn on a map of the test area using the computed data cell scores, and, for control points, centers of the 1-km squares. The products were two factor maps, each delineating the area dominated by the effects of one of the factors. The isopleths show the varying degree of intensity of the effects. Delineation was accomplished by the zero value isopleths; positive scores measured intensity of effects, and on the other side of the zero isopleths, negative scores reflecting negatively loaded variables measured "negative" intensities.

The overall result was that, on the basis of the parameters used, the test area was divided objectively and quantatively into its two major geomorphic subareas which were also ranked in order of importance of geomorphic effects by the factor analysis. The first subarea consists of the elevated dissected Coastal Plain. The second subarea consists of the lower areas—the partly flooded terraces, flooded valleys, and tidal marshes—the area of maximum land-water interfaces.

The results of this experiment in the application of factor analysis to quantitative terrain parameter data suggest that the method could be successfully adapted to similar data matrices such as those which may be derived in remote sensing systems for the purpose of classifying areas for land use or economic resource potential.

Preglacial Kentucky River

Geologic mapping in northern Kentucky has delineated an abandoned river channel 200 to 250 ft above the modern channel of the nearby Ohio River. The valley is traceable over a distance of about 40 mi. As interpreted by W. C. Swadley (1971), geologic evidence indicates the valley is a segment of the preglacial Kentucky River which formerly drained northeastward. Ponding by probable Nebraskan Glaciation caused the river in this segment to reverse its preglacial direction of flow. The valley was later overridden by the advancing ice sheet and, because it became filled with till, was not reoccupied when the ice retreated.

Preglacial erosion surface in northern Michigan

J. W. Whitlow reports that relief on the Freda Sandstone in the Greenland quadrangle, Ontonagon County, Mich., is as much as 475 ft, a little less than the relief on the Jacobsville Sandstone south of the Portage Lake Lava Series in the Rockland quadrangle, Ontonagon County, Mich. A prospect hole in NW¼NW¼NW¼ sec. 18, T. 51 N., R. 37 W., Greenland quadrangle near the West Branch Firesteel River penetrated 467 ft of valley fill alluvium over shale. The bottom of the valley fill is 220 ft below the present level of Lake Superior. Test borings at each side of the Flintsteel River in SW¼, sec. 18, T. 51 N., R. 38 W., Greenland quadrangle penetrated 70 ft of overburden on what the road engineers called hardpan, which is believed to be Freda Sandstone. Evidence indicates the valley of the Flintsteel River is not as deep as the valley of the Firesteel River.

Hydraulic geometry of Alaskan streams

The proposed trans-Alaska pipeline and transportation corridor spans Alaska from Prudhoe Bay on the North Slope to the southern port of Valdez and traverses areas where little or no hydrologic data are available. W. W. Emmett reported that channel geometry surveys were conducted at gaged and ungaged locations along the corridor south of the Yukon River so that magnitude and frequency of river flows can be estimated. The surveys were conducted during 2-week periods in September 1970 and in September 1971.

Runoff is characterized by a bankfull discharge having an occurrence interval of about 1.5 yr. In the southern half of the

studied area, the south-central hydrologic subregion, bankfull discharge Q_B (in cubic feet per second) has a magnitude related to drainage area DA (in square miles) of $Q_B \propto DA^{0.97}$. In the northern part of the area, the Yukon River hydrologic subregion, bankfull discharge has a magnitude of $Q_B \propto DA^{0.79}$. The runoff relationships for the two regions coincide at about 100 sq mi, and bankfull runoff is equal to 10 cfs per sq mi. The average annual discharge has a flow duration of about 35 percent of time and a ratio of discharge to bankfull discharge of about 0.20 in the south-central subregion and about 0.25 in the Yukon River subregion. The ratio of discharge to bankfull discharge for flood stages at gaging stations is not as consistent as it is for within-channel flows. For the 50-yr flood, the ratio of discharge to bankfull discharge is about 2.8 in the south-central subregion and about 4.0 in the Yukon River subregion.

Many of the hydrologic variables and their interrelationships have been determined from field observations and office computations. These include flow depth, channel width, flow velocity, discharge, drainage area, channel slope, and bed- and bank-material particle-size distributions. Determination of these relationships has enabled estimates to be made of depth of riverbed scour and amounts of bedload transport.

Erosion rates in the Transverse Ranges in California

A study by K. M. Scott and R. P. Williams of major-storm and long-term erosion rates in 35 small watersheds (0.25-17.60 sq mi) in the Transverse Ranges in California indicates that rates range from low values for watersheds not requiring catchment or channel stabilization structures to erosion rates as high as any recorded in the United States for comparable bedrock. The reason for this extreme variability is the high degree of tectonic activity in the area. Watersheds are locally being uplifted by as much as 25 ft per 1,000 yr, yet the maximum extrapolated rate of denudation measured over the longest available period of record is 7.5 ft per 1,000 yr adjusted to a drainage area of 0.5 sq mi. Consequently, many landscapes within the Transverse Ranges are more a function of tectonic activity than of erosional processes.

To define major-storm erosion rates quantitatively in the Transverse Ranges, a comparable group of 37 watersheds with measured sediment catchments resulting from the catastrophic 1969 storms in the area was selected. Sediment yields from this group of watersheds in 1969 ranged from moderate to amounts equivalent to reduction of the entire surface of the watershed by more than 2 in. Much 1969 sediment transport occurred in the form of debris flows which mobilized most channel-bed material and were triggered partly by slope failures of various types.

Correlation of erosion rates between watersheds having measured sedimentation rates and those having unknown rates required definition of the chief variables controlling the rate of erosion. Numerous types and combinations of variables measuring physiography, soil erodibility, wildfire effects on cover, hydrologic factors, vegetation, and land use were fitted to multiple-regression equations having sediment yield as the dependent variable.

Another variable proving significant in all final regression analyses was a measurement of the degree of watershed instability. This variable was the percentage of watershed area underlain by slope failures, a logical measure of increased erodibility either in response to lowered base level by regional uplift or to differential uplift within a drainage basin. Several of the 72 watersheds are on frontal escarpments of mountain blocks and are cut by active thrust faults along which the upper part of the basin is overthrusting the lower part of the basin or the adjacent valley floor.

Degradation of Earthquake Lake outflow channel

River profiles made by M. V. Johnson and R. J. Omang show that the Madison River is downcutting through the Madison slide, which was caused by the Hebgen Lake, Mont., earthquake of August 17, 1959. Since July 15, 1960, the crest of the outlet channel of Earthquake Lake has been lowered about 4 ft by natural cutting. The outlet channel has degraded as much as 19 ft in one short reach. Degradation of the channel was as much as 8.5 ft during the 1971 spring and summer runoff. Natural cutting is expected to continue until the slope of the channel has adjusted to provide only the velocities necessary to transport the river's sediment load. Downcutting through the landslide may endanger some engineering structures and cause environmental changes in the river below the landslide area.

Extent of debris avalanches on hillslopes

In a study of erosion and deposition resulting from the rains of Hurricane Camille in Virginia, G. P. Williams (1972) and H. P. Guy found the upslope tips of debris avalanches are generally at the steepest part of the hillside. This location in most cases marks the point where the convex upper zone of the hillside profile meets the concave or straight section immediately below, a point which varied from 0.3 to 0.95 of the horizontal distance from the base to the top of the hill.

GROUND-WATER HYDROLOGY

Areas of research in ground-water hydrology reflect the widespread concern for improved management of one of our most valuable resources. The development of simulation modeling techniques has permitted the interactive nature of the hydrologic system to be analyzed to a degree heretofore not possible. Digital-computer models that permit quantitative evaluation of problems involving movement of chemical contaminants or heat in the ground-water environment are being developed. Digital and analog models are being used to assess the state of knowledge of boundaries and hydrologic properties of aquifers by simulating known historical stresses

and comparing model responses to observed responses. If the comparison is acceptable, these models can be used to predict the response to future stresses on the aquifer, and the simulations will provide bases for water managers to evaluate the benefits of various development schemes. Capability is being developed to interface digital computers with electric analog models, which will result in a reduction in time and cost to analyze hydrologic systems.

Artificial-recharge tests are being conducted in different types of ground-water systems with the following objectives: (1) Temporarily storing fresh water in brackish-water aquifers for withdrawal when needed at some later time, (2) connecting, by means of a well, a fresh-water aquifer with higher head to a brackish-water aquifer with lower head to continuously transfer fresh water into the brackish zone, (3) connecting a shallow water-table aquifer to a deeper confined aquifer with lower hydraulic head to recharge the lower aquifer with water that otherwise would be discharged from the shallow aquifer by evapotranspiration or to streams.

New analytical techniques were developed to determine hydraulic characteristics of confining beds. In response to the need for information on the movement of contaminants in the subsurface, analytical methods and field techniques have been developed to determine the hydraulic-dispersion characteristics of aquifers. Studies continue on the hydrogeology of carbonate terranes to determine how, when, and where permeability is formed in carbonate rocks. A method was devised for determining the hydrologic properties of the unsaturated zone through analyses of fluctuations of the water table resulting from barometric changes. Economic considerations in ground-water systems are receiving attention. Techniques were developed for analyzing the design of water-level networks to minimize data collection costs while retaining an acceptable level of information. An analysis was made of the relative impact of hydrologic and economic factors in managing regional ground-water systems.

Chemical constituents and heat in ground-water systems

P. C. Trescott studied the problem of salt-water intrusion across an aquitard based on the calculable position of the salt-water front in an aquifer. The mathematical model, which includes the osmotic membrane effect of clay in an aquitard, is being applied to a Cretaceous aquifer system in the Maryland coastal plain where proposed heavy pumpage will eventually induce movement of brackish water through aquitards into the pumped aquifer. Membrane properties of the aquitard material are being measured in the laboratory by R. G. Wolff.

G. F. Pinder reported that a numerical technique, the Galerkin method, has been applied to the problem of predicting movement of chemical contaminants in the subsurface. Studies showed the method of finite differences, which has been widely used for ground-water flow problems, may introduce an undesirable phenomenon called numerical dispersion in transport problems which can result in erroneous solutions. The Galerkin method permits the area being studied to be divided into irregularly shaped subareas with curved edges; as the study progresses, the subarea boundaries may be changed to better represent the dynamics of the physical system. G. F. Pinder and J. W. Mercer are applying this method to the solution of two-dimensional problems involving movement of chemical contaminants or heat. The method is being tested using data from the hydrothermally active area near Wairakei, New Zealand.

Aquifer model studies

A study of the Chicot aquifer of southwestern Louisiana by A. L. Zack involved the construction and verification of an electric analog model. The model was used to predict water-level trends resulting from anticipated ground-water withdrawals through the year 2020.

Flow rates calculated from transmissivity data and the predevelopment potentiometric surface are being used by J. C. Halepaska (Kansas Geol. Survey) and D. B. Richards (USGS) in a steady-state digital-computer model of the Little Arkansas River basin in south-central Kansas. Water-level changes computed by the model agree closely with historic changes caused by withdrawals of ground water by wells in the parts of the basin where field data are available. Additional field data are required for basin-wide verification of the model.

A digital-computer model study of Glynn County, Ga., by J. D. Bredehoeft, G. F. Pinder, and H. B. Counts indicated that water containing 500 mg/l chloride in the upper zone of two water-bearing zones will reach the edge of the well field of a large industry by 1975 if the present discharge pattern continues. According to the model results, a discharge of 4,500 gpm from an interceptor well system between the high chloride source and the well field would prevent the high chloride water from reaching the field.

Continuing investigations of the Magothy aquifer in the Annapolis, Md., area, by F. K. Mack, indicated that the hazard of salt-water contamination may be the limiting factor in the development of the aquifer. About 30 ft of clayey silt and fine sand in the overlying Matawan Formation protects the Magothy aquifer from the saline water of Chesapeake Bay and its estuaries in most parts of the project area. A digital-computer model, developed by P. C. Trescott, of the Matawan Formation indicated that it would take 10 yr for water to move through the Matawan Formation to the underlying Magothy aquifer under the hydraulic-head differentials resulting from pumping at a rate of 60 mgd from the hypothetical array of wells used in the analysis.

A geohydrologic study of the Englishtown aquifer in the northern coastal plain of New Jersey, by W. D. Nichols, involved development of a digital-computer simulation model. The model was verified by matching simulated aquifer response with historic water-level decline data for the period 1959–70. The simulation model considers transient leakage from the underlying and overlying confining beds and steady

leakage into the Englishtown aquifer from the overlying Mount Laurel aquifer.

A digital-computer model was used by O. J. Cosner to analyze the ground-water system in the Franklin area in Virginia. The thickness and permeability of the confining layer and the transmissivity of the aquifer were adjusted until the model successfully approximated the potentiometric surfaces observed in September and October 1970 and December 1971. The pumping history simulated was for the period 1891 through 1971.

R. W. Davis (USGS), R. O. Plebuch (USGS), and H. M. Whitman (Kentucky Geol. Survey) used a digital-computer model analysis to show that the rapidly declining heads in a hydraulically isolated deep Pennsylvanian aquifer in the western coal field region of Kentucky reflect that the aquifer has small values of transmissivity and storage coefficient and has not received any recharge.

A digital-computer model was used by J. E. Luzier and J. A. Skrivan to analyze the basalt aquifer system near Odessa, Wash. The model approximated to an acceptable degree water-level declines during the period 1967–71. The model was used to compare water levels in 1981 to (1) withdrawals continuing at 1970 rates, and (2) withdrawals at the maximum legal rate.

An electric analog model of the sandstone aquifer, the principal aquifer of the Madison, Wis., area, was developed and verified by J. B. Gonthier. The aquifer was modeled as a leaky artesian system. Analog model evaluation of proposed expansion of the water-supply capacity of the Madison Water Utility indicated that a progressive decline of aquifer water levels will result from the increased pumping. Drawdown and interference among the utility's supply wells and wells of other municipalities and industries, however, should not be sufficient to cause serious problems.

A digital-computer model analysis by R. S. McLeod indicated that the sandstone aquifer in Dane County, Wis., is adequate to meet the water needs of the county through the year 1990. The effects of ground-water withdrawals from this aquifer on the base flow of streams and on the overlying water-table aquifer are being investigated.

Improved efficiency of electric analog models

A data-acquisition and control system to be used with electric analog models which simulate hydrologic systems is under development. The design includes a small digital computer which will be linked through appropriate interfacing equipment with existing analog computers. In general, the new system will facilitate the acquisition and processing of data from analog computers, thus resulting in a reduction of time and costs.

Specifically, digital acquisition of data will help eliminate errors in readout and will provide the opportunity to manipulate data and to display it graphically using automatic plotters, printers, or CRT screens. The new system will provide the designer and user of hydrologic analog models with the means of rapid examination of the response of a modeled system and allow some types of modifications to be made while online with the digital computer. In addition, the use of automatic control will greatly extend the capability of the system to simulate the complex input functions required to stress the analog model.

The system is being implemented with a small high-speed digital computer having a core capacity of 12,000 words. Software includes a supervisor program which facilitates program development and the operation of user programs. Control of the analog system is accomplished through digital-to-analog converters which are set under program control. Analog signals from these converters either are applied directly to the analog system or are used to trigger electronic function generators that in turn activate the system.

Data are collected from the analog model through a 1,000-point crossbar scanner. The voltage at each point scanned is channeled to an analog-to-digital converter where it is transformed and stored in the computer. Data can then be printed, displayed, or stored for further processing.

Artificial recharge

G. G. Ehrlich, T. A. Ehlke, and John Vecchioli continued research on well recharge with treated-sewage effluent at Bay Park, N.Y. Injection of unchlorinated treated-sewage effluent into an experimental recharge well screened in the Magothy aquifer resulted in a high rate of clogging. The comparison of this clogging with that observed in earlier tests indicated that microbiological growths around the well screen caused the clogging. These growths were inhibited when the injected effluent was chlorinated. Travel of pollution-indicator bacteria injected into this sand aquifer was limited to distances of less than 20 ft. Geochemical studies have shown that the injected treated-sewage effluent is chemically compatible, in general, with native water in the Magothy aquifer. However, some cation exchange has been observed. Also, the injected water was found to be more corrosive to iron metal than the native water. This higher rate of corrosion is attributed to the catalytic action of sulfate-reducing bacteria, which presumably are more active in the comparatively nutrient-rich injected water.

S. J. Tyley reported that about 175 acre-ft of water has been recharged to a test pit in the alluvial sand and gravel water-table aquifer in the upper Coachella Valley, Calif., over a period of 125 days. The recharge test pit is 150 ft long, 50 ft wide, and 4 ft deep. The recharge rate varied from 5 to about 20 ft per day. The depth to the water table is about 500 ft. An estimate, based on analyses of water-level variations and changes in chemical quality of water, indicated that the recharge reached the water table in about 7 months.

In research studies of artificial recharge of the Ogallala Formation in the High Plains of Texas, R. F. Brown and W. S. Keys used cyclic diurnal temperature fluctuations of injected

surface water to measure the flow characteristics of the recharge water. Recharge water that is colder or warmer than ground water can be identified by geophysical logging in observation wells. As this thermally distinctive water moves through the aquifer, the temperature logs indicate the rate of movement. Attenuation of temperature gives a rough measure of hydraulic dispersion. Results of one field experiment in the Ogallala Formation indicated that movement of injected recharge water takes place mainly through solution channels in high-carbonate zones. These channels transmitted turbid recharge water 35 ft in less than 4 hr.

Continued studies of artificially recharging fractured carbonate rocks in Minnesota by H. O. Reeder showed that the efficiency of a recharge well can be improved by designing the injection pipe small enough to restrict the flow rate to the anticipated recharge rate. Positive pressure in the inlet pipe can be maintained by utilization of pipe friction instead of a down-hole valve. The maximum flow rates through heavy-duty pipes used in the experiment are about 73 gpm through 1¼-in. pipe and 109 gpm through 1½-in. pipe. The temperature and viscosity of the water affect the maximum-flow rates. For a temperature change from 14.0°C to 11.2°C the measured flow rate decreases in the 1½-in. pipe from 100.0 gpm to 90.0 gpm as compared to a computed 92.6 gpm. One experiment involved injecting water into a recharge well at about 100 gpm for 20 days. The pressure effects were transmitted rapidly and chemical analyses showed that the injected water traveled to the lower part of an observation well 99 ft distant.

D. L. Brown reported that 198,320 gal of treated water was injected at a rate of 400 gpm into a brackish-water confined sand aquifer at Norfolk, Va., in November 1971. Seventeen hours after the injection phase was completed, the well was pumped at 720 gpm. The test results indicated that 84 percent of the injected volume of water withdrawn contained less than 250 mg/l chloride and 1,000 mg/l total dissolved solids. Preliminary analyses of the data showed that (1) minor clogging of the sand reservoir occurred during the injection but was cleared up during the withdrawal pumping, (2) a decrease in specific capacity of approximately 8 percent at a pumping rate of 500 gpm occurred as a result of the injection test, (3) head buildups in excess of the predicted values occurred in the injection pipe and annular space between the injection pipe and the well but did not occur in the observation wells, and (4) although some chemical reactions took place between the fresh and brackish water, no significant clogging of the aquifer due to precipitates was apparent.

W. C. Sinclair conducted studies in west-central Florida (Hillsborough, Pasco, and Pinellas Counties) to determine the feasibility of recharging the Floridan aquifer in areas where it is separated from a surficial water-table aquifer by clayey materials of low permeability. Although the head in the water table aquifer is 10 to 15 ft higher than the head in the Floridan aquifer, the clayey material separating the aquifers greatly limits the natural leakage. Because the water table is relatively shallow in this area, recharge during wet periods results in swampy conditions. Much water is discharged from the surficial aquifer as evapotranspiration. Connecter wells, open to the water-table aquifer, cased through the clayey zones, and open to the Floridan aquifer, would permit continuous transfer of water to the lower aquifer. As a result the water table would be lowered and the rate of evapotranspiration reduced. Furthermore, excess surface water, when available, could be spread over these areas. Infiltration tests were conducted on two prevalent soil types. Each test site was 50 ft in diameter and contained undisturbed natural vegetation. Profiles of moisture content of the surficial sand from land surface to the water table were made by neutron probe before, during, and after the sprinkling of water in simulation of rainfall of various intensities. The more permeable soil has an infiltration rate of about 50 gpd per sq ft. Water spreading on this soil, in conjunction with connecter wells between the water table and the Floridan aquifers, should be a feasible method for increasing recharge to the Floridan aquifer.

W. E. Wilson reported that during 1971, in a 42-sq-mi citrus grove in DeSoto County, Fla., irrigation pumpage from the confined Floridan aquifer was about 4,570 million gal. Although more acreage was under cultivation and pumpage was more than twice that of the preceding year, during the nonirrigation summer months the potentiometric surface recovered to about the 1970 level. During the wet season, water levels in the surficial water-table aquifer tend to rise to an undesirably high level, and measures are taken to drain the excess water out of the area. Test holes have been drilled to determine a favorable site for the installation of a connecter well. The connecter well will be screened in the shallow sand aquifer and drilled into the upper part of the underlying limestone aquifer. Because of an initial head difference of about 40 ft, ground water should move naturally and continuously through the connecter well to recharge the artesian aquifer.

C. H. Tibbals conducted artificial-recharge experiments at a Cocoa, Fla., well field. The municipal-supply wells obtain water from the Floridan aquifer and several of the wells normally yield water with a chloride content greater than 400 mg/l. A siphon was installed to connect a shallow fresh-water well, drilled into a shell bed within the marl and clayey sands which overlie the Floridan aquifer, to an unused city well. The siphon, a 3-in. diameter plastic pipe, is presently transferring fresh water to the Floridan aquifer at the rate of about 90 gpm.

A pilot connecter well has been in operation for a year in the southwestern part of Orange County, Fla. The connecter well permits transfer of water from an unconfined sand aquifer to an underlying confined limestone aquifer by gravity flow, thus lowering the water level in the sand aquifer. The sand aquifer is made up of three parts—an upper sand layer about 20 ft thick, a hardpan layer about 20 ft thick, and a lower sand layer about 40 ft thick. The screen in the connecter well is set in the lower sand. F. A. Watkins, Jr., reported that the

well is transferring water from the sand aquifer to the limestone aquifer at a rate of 13 gpm or 21 acre-ft per yr. The effect of this transfer of water has been to lower the water level significantly in the lower part of the sand aquifer about 18 ft at the connecter well and about 6 ft at a well 105 ft from the connecter well. It has not significantly affected the water level in the upper part of the sand aquifer, however, because the lower permeability of the underlying hardpan layer acts as a semiconfining bed and tends to retard the downward movement of the water from the upper sand layer to the lower sand layer. An analysis of a gamma-ray radioactivity log made in the connecter well in September 1971 showed a high count at the bottom of the casing. This high count was interpreted as reflecting a buildup of organic material. The source of the organic material is believed to be the sand aquifer, which contains colored water and has a pH of about 5, whereas the water from the limestone aquifer has a pH of about 8. Thus, it is postulated that when these two waters mix, the organic material precipitates and is concentrated in the rock near the bottom of the casing.

Characteristics of confining beds

S. S. Papadopulos and R. G. Wolff developed an analytical solution to the problem of nonsteady vertical ground-water flow through a two-layer confining bed. The solution was used to analyze data from piezometers placed in multilayered confining beds at Alamosa, Colo.

A multilinear regression analysis of clay compaction in the Houston, Tex., area was made by D. G. Jorgensen to define compaction for an analog model of the aquifer system. It was found (1) that most of the compaction occurs in clay layers in the upper aquifer, (2) that compaction of sand layers is small, (3) that compaction of clay and subsidence of the land surface is directly related to artesian-pressure decline, and (4) that clay thickness is a significant parameter.

D. C. Signor reported that laboratory experiments of recharge of montmorillonite clay-water mixtures (clay concentrations from 200 to 500 mg/l) into sand columns show that that the clogging effects of the different clay concentrations vary by an order of magnitude. At pressures of 2 kg/cm^2 the major effect of clogging took place in a matter of hours, and the hydraulic conductivity of the column was reduced by as much as 80 percent.

W. D. Nichols used analytical techniques to estimate transient and steady leakage into the Englishtown aquifer in New Jersey. The evaluation of transient leakage was based on Terzaghi consolidation theory and analytical solutions for the hydrodynamic model of Hanshaw and Bredehoeft (1968) that describes nonsteady fluid flow in low permeability sediments. Results indicated that water released from and flowing through the adjacent confining beds was about 94 percent of the 30.2 billion gal of water withdrawn from the aquifer between 1959 and 1970. As much as 37 percent of the water withdrawn from the Englishtown aquifer from 1959 through 1970 was replaced by water released from storage in the adjacent confining beds. An additional 57 percent of the withdrawal over this time period was supported by steady leakage through the overlying confining layer from the Mount Laurel aquifer. Only about 6 percent of the water pumped is accounted for by a reduction of water in storage in the aquifer. This small net change in the volume of water stored in the aquifer occurred as a result of declines in head of from 100 to 140 ft around centers of pumping over the 12-yr period.

R. G. Wolff reported that field and laboratory estimates of hydraulic diffusivity of a heterogeneous confining bed in the San Luis Valley, Colo., differed considerably. Indications are that lenses of more permeable sediments, which were not detectable by the geophysical and geologic methods used, may be present. These lenses may have permitted short-circuiting during the field tests. Therefore, it is necessary to have detailed knowledge of the complex geometry of alluvial deposits before laboratory determinations can be transferred to field application.

Hydrology of carbonate-rock terranes

Research on the hydrology of carbonate-rock terranes by H. E. LeGrand and V. T. Stringfield (1971) demonstrates that patterns in the development and distribution of permeability can be identified and used effectively. A technique of reconstructing the hydrogeologic history of a carbonate-rock terrane helps to evaluate the permeability of an aquifer and to distinguish between currently developed aquifers and paleo-aquifers. Unusual patterns of circulation of water occur locally in coastal karst regions. From the results of studies on Andros Island, Bahamas, and at Split, Yugoslavia, the effects of karst features on the relation of fresh water to the sea water in carbonate rocks of coastal areas were better defined by Stringfield and LeGrand (1971). Integrated evaluations of the distribution of permeability in coastal karst regions and of the principles relating to the dynamic balance between fresh aquifer water and sea water are leading to better knowledge of methods that may be used to salvage much of the karst water which presently is lost to the sea.

Barometric fluctuations in water-table aquifers

Barometric fluctuations in water-table aquifers, the magnitudes of which are dependent on the rate of barometric change, may be computed by treating the material above the water table as a layer that is of limited permeability to air. The computations are based on an average effective pneumatic diffusivity, defined as the relative permeability to air of the material in the unsaturated zone at the prevailing moisture content divided by the drained porosity. In a study by E. P. Weeks, different effective pneumatic diffusivities were used with a one-dimensional digital model to compute barometric effects, and the computed effects were compared to observed water-level fluctuations to determine the diffusivity value best

describing that of the unsaturated zone. The method may be useful for correcting water-level measurements for barometric effects when such effects are large. Also, the method may be useful for estimating the hydraulic conductivity of the unsaturated zone in areas where the sediments above the water table are relatively uniform.

Effects of a heated pipeline on ground-water flow in Alaska

Discharge of ground water through the thaw bulb around a heated buried pipeline poses a serious threat to pipeline stability if a quicksandlike condition develops. Model studies by C. E. Sloan and J. D. Bredehoeft of ground-water flow near a heated pipeline buried in relatively permeable sand and gravel indicate that high artesian pressures are not likely to occur beneath a seasonally frozen layer. This finding is generally confirmed by test drilling along the proposed trans-Alaska pipeline route. Quicksandlike conditions resulting from the upward flow of water near the pipe do not appear likely except where the pipe is buried in fine sand or silt overlying a more permeable layer of coarse sand or gravel. A heated trench of permeable material along the pipeline will focus ground-water discharge at the pipeline, especially in winter. This discharge will increase the number and frequency of icings near the pipeline.

Ground-water network design

In January 1971, a cooperative project was initiated by the USGS and the Hydrological Service of Israel to develop system analytic techniques for the design of ground-water data-collection systems. N. C. Matalas and J. R. Slack analyzed water-level data and used statistical techniques of correlation and regression. These techniques provided a means for evaluating the information transfer from well to well as a function of time. Strategies for minimizing data-collection costs subject to information constraints were developed. Risk evaluation of decisions to reduce observation sites and frequencies of observation were considered.

Analysis of relative impact of hydrologic and economic factors on ground-water management

Thomas Maddock III provided methodology (1) to determine utility loss due to errors in the hydrologic and economic parameters of ground-water-management models, (2) to rank a model's parameters in terms of error effect and in terms of priority for further data collection, and (3) to determine how best to distribute funds between different parameters' data collection. The methodology combines management models explicitly with ground-water models.

Salt-water movement across a fault zone

C. D. Whiteman, Jr., reported that salt-water encroachment in the "600-ft" sand of the Baton Rouge, La., area is apparently being fed by salty water moving across the Baton Rouge fault from the "400-ft" sand south of the fault. Test drilling has confirmed that the "400-ft" sand south of the fault was displaced downward more than 200 ft and now is in contact with the "600-ft" sand north of the fault. Water quality is similar across the fault. Although a head difference of 45 to 55 ft exists across the fault, hydraulic continuity between the sands was demonstrated when cyclic pumping of a test well north of the fault produced subdued but corresponding drawdown and recovery cycles in observation wells south of the fault. The fault thus acts as a thin zone of low permeability separating two highly permeable aquifers. The zone of low permeability limits the rate of salt-water movement from the "400-ft" sand to the "600-ft" sand. Encroachment of salt water may be expected to continue as long as a high gradient is maintained across the fault.

Salt-water encroachment

Studies by R. K. Gabrysch and G. D. McAdoo showed that ground-water withdrawals in the Orange County, Tex., area increased about 12 percent (2.4 mgd) during the period from 1962 to 1970. The increased withdrawals resulted in water-level declines of as much as 60 ft in the area of greatest pumpage. Encroachment of saline water by lateral or vertical movement was reflected by a large increase of chloride concentration near the center of pumpage from 240 mg/l in 1963 to 860 mg/l in 1970. Because areas similar in geology and hydrology have experienced land-surface subsidence as a result of large water-level declines, bench marks in Orange County were resurveyed to determine if similar subsidence had occurred. The elevations of bench marks in 1969 generally differed less than 0.5 ft from elevations obtained in previous surveys dating back to 1916, which is interpreted to indicate that little or no subsidence has occurred.

Hydraulics of inner Piceance Creek basin

J. E. Weir, Jr., reported that water-level fluctuations in two separate aquifer units in Colorado (lower Parachute Creek and Douglas Creek Members of the Green River Formation) respond correlatively to stresses which might be caused by injection of water into the Parachute Creek Member elsewhere in the Piceance Creek basin. Five core holes from 900 to 2,500 ft deep, drilled into the Green River Formation in the southern inner basin by the Oil Shale Corp., were hydraulically tested. Transmissivities estimated from these tests indicate that some fracture zones in each of the aquifers have undergone considerable enlargement by solution while others have remained relatively unaffected. In every hole tested the Mahogany Ledge zone (bed within the upper part of the Parachute Creek Member) yielded considerable water; thus, the previously accepted concept that the Mahogany Ledge zone is an aquiclude is not valid for the south-central inner basin.

Evaluation of water-level decline in basalt aquifer

R. D. MacNish and R. A. Barker reported that recent water level declines of 20 ft per yr in the basalt aquifer underlying the Walla Walla River basin, Washington, are more likely the result of increased pumpage rates (265-percent increase since 1950) than a permanent loss of water from storage. Since 1950 pumpage totaled 380,000 acre-ft and the average potentiometric head declined 50 ft over an area of about 150 sq mi. Using a conservatively large coefficient of storage of 0.005 for this artesian aquifer, it was computed that the net change in aquifer storage was 25,000 acre-ft (a decrease of about 10 percent), which indicates that at most 10 percent of the water pumped from the aquifer reflects a reduction in storage in the basalt aquifer.

Regional specific yield of the Edwards Limestone

R. W. Maclay and P. L. Rettman estimated the average regional specific yield of the Edwards Limestone and associated limestones to be 0.02. The estimate applies only to the rock in the upper 80 ft of the aquifer, through which water levels fluctuated during the period 1957–66. The regional specific yield was calculated to be the ratio of the difference between recharge and discharge, measured in feet, to the average change in water level in 10 selected observation wells. Estimates for individual years ranged from 0.016 to 0.026. No correlation could be determined between aquifer stage and the annual estimates of specific yield.

Estimating hydraulic dispersion from tracer tests

D. B. Grove and W. A. Beetem (1971) have developed a field method of estimating aquifer porosity and the coefficient of hydraulic dispersion. Water is pumped out of one well at a steady rate and injected into another well at the same rate. When steady-state conditions are approximated, a specific amount of a tracer is injected into the pipe connecting the well pair. The variation through time of the concentration of tracer at the discharge well is analyzed to determine porosity and hydraulic dispersion. Analysis of test results in a fractured carbonate aquifer near Carlsbad, N. Mex., indicated a porosity of 12 percent and a hydraulic-dispersion constant of 125 ft. These values are consistent with known properties of the aquifer.

A similar hydraulic dispersion test of a thin sand aquifer of valley-fill origin in the San Luis Valley, Colo., was conducted by R. G. Wolff. Sodium chloride was used as the tracer. The change in concentration of sodium chloride through time at the pumped well was determined by measuring electrical conductivity of the fluid. Preliminary analyses of test data indicate a very low coefficient of dispersion, which is interpreted to suggest that all the flow was conducted through a small part of the aquifer.

SURFACE-WATER HYDROLOGY

The objectives of research in surface-water hydrology are to define the magnitude and variation of streamflow in time and space, under both natural and manmade conditions, to understand the flow process in stream channels and estuaries, and to define the rates of movement and dissipation of pollutants in streams.

Turbulence in open-channel flow

R. S. McQuivey (1972) developed new techniques for measuring turbulence characteristics in open-channel flows. He summarized turbulence data from rivers, conveyance channels, and laboratory flumes and also related turbulence intensities and the scales of turbulence to the basic mean hydraulic parameters. Attempts to relate turbulent diffusion coefficients to turbulence characteristics had limited success.

H. J. Tracy measured the mean and turbulent components of flow in an experimental channel consisting of a 12- by 12-in. main channel section and a 4- by 8-in. overbank section. The mean-flow pattern was found to be almost symmetrical in the main channel section, departing from symmetry at less than 2 in. from the common boundary of the two sections. The smaller section apparently supresses turbulent fluctuations developed in the main section, but only in the longitudinal and horizontal directions; fluctuations in the vertical direction do not seem to be greatly affected by the adjoining section. The shear stress at the common boundary is not zero but varies as the velocity gradient across the boundary.

Applications of dye tracing

Time-of-travel and dispersion characteristics of a 113-mi reach of the Wind-Bighorn River from Boysen Dam to Greybull, Wyo., were measured twice in 1971, according to H. W. Lowham and J. F. Wilson, Jr. (1971). For each measurement a single slug of Rhodamine WT dye was injected below Boysen Dam and was monitored as it passed seven downstream locations. Traveltimes of the peak concentration were 56 hr for a discharge of 1,940 cfs at Boysen Dam and 33 hr for a discharge of 8,280 cfs at Boysen Dam. The dye cloud for the smaller discharge took 12 hr to pass Greybull and, for the larger discharge, 6.7 hr.

L. A. Wagner and P. H. Hamecher used dye tracing to determine the distribution of waters at the junction of the Barge Canal and the Genesee River near Rochester, N.Y. The proportion of relatively high quality Barge Canal water that flows into the Genesee River is a factor in the design of pollution-abatement facilities in metropolitan Rochester. During a low-flow period when the discharges of the river and the canal above the junction were about equal, results of the dye study indicated that 40 percent of the flow of the river below the junction was derived from the canal.

Streamflow characteristics related to physical and climatic characteristics of drainage basins

P.C. Bent related streamflow characteristics at 139 gaging stations in Michigan to topographic and climatic characteristics of the drainage basins by multiple regression. After adding a parameter based on estimated relative permeability and on the areal extent of various geologic surface formations in each basin, he recomputed the regressions. The improvement by including the geologic parameter is indicated by the following reductions in standard errors of regression: from 89 to 64 percent for low flows, from 37 to 26 percent for high flows, from 51 to 38 percent for peak flows, from 36 to 29 percent for mean flows, and from 38 to 34 percent for standard deviations.

P. R. Jordan and T. J. Irza related peak-flow frequency characteristics to drainage area, rainfall intensity, stream length, and stream slope in Kansas. For drainage areas smaller than 200 sq mi, the standard errors of the 50-yr flood are about 80 percent in western Kansas and 59 percent in eastern Kansas. For larger drainage areas the respective standard errors are 60 and 45 percent.

A. G. Scott (1971) defined flood-peak characteristics in New Mexico in terms of selected physical and climatic characteristics.

Hydrologic modeling of small basins

In calibrations of a semideterministic rainfall-runoff model, H. C. Wibben noted a tendency of the model to overestimate summer peaks and to underestimate winter peaks when both types were used for calibration. This result is ascribed to the model's averaging the changing effects of vegetation throughout the year. At some sites, two calibrations, one for summer and one for winter, may be warranted. The calibrated models will be used to generate long-term records of peak flows.

F. E. Arteaga developed a rainfall-runoff relation from storm-event data on a 330-acre semiarid watershed near Apache Junction, Ariz. Rainfall-excess data were obtained from two linear equations, using rainfall intensity and antecedent conditions as variables. The rainfall-excess data were then distributed by the unit-hydrograph method to determine the peak flow.

S. E. Rantz (1971) in a study of drainage-design criteria for the San Francisco Bay region, California, devised a method of transposing storm data for use in the hydrologic modeling of small basins. Such modeling often requires that storm-precipitation data be transposed to an ungaged study basin from the nearest recording rain gage. In mountainous terrain where precipitation magnitudes vary widely over short distances, transposed values may be biased if it is assumed that the ratio of precipitation during short intense storm bursts at two sites equals the ratio of mean annual precipitation at the two sites. In a mediterranean climate, such as that of the California coastal area, the relative simplicity of the regimen of precipitation makes it possible to manipulate depth-duration-frequency data to provide variable ratios for transposing storm-precipitation data that have been subdivided in short time increments.

Dissipation and transport of heat in surface waters

Nobuhiro Yotsukura and C. R. Faust combined the diffusion method developed by Yotsukura and E. D. Cobb (1972) with the exponential decay law of excess heat to calculate the longitudinal and transverse distribution of water temperature downstream from effluent sites. Computed temperatures were within 1°C of observed temperatures when river and effluent discharges were steady and water temperature was observed far enough downstream (1,000 or more times depth) so that there was no temperature stratification with depth. A transverse diffusion coefficient of 0.6 times shear velocity times depth and a surface heat transfer coefficient which ranged from 0.02 to 0.10 fph provided the best fits to the data; these coefficients agree with coefficients determined from other studies. The equilibrium temperature method should not be used for hourly or other short-term heat calculations; use of a simple linear method based on the daily average water temperature is proposed for short-term heat calculations.

Flood-frequency analysis

A preliminary study of the effects of outliers of flood-frequency analyses by W. H. Kirby indicated that outliers degrade the accuracy of the mean and standard deviation of some 10 percent of random samples drawn from skew populations. For skews greater than about 2, for example, the root mean square error of estimates affected by outliers was of the order of 50 percent to more than 100 percent greater than that of unaffected samples. (In this context, an outlier is merely an observation which is drawn from the same statistical population as the rest of the sample but which is much larger than the other observations.) It was found that the effects of such outliers were nullified by taking a suitably weighted average of the estimate based on the full sample and the estimate obtained by ignoring the largest observation.

Stream temperatures

H. N. Flippo, Jr., analyzed stream-temperature data in Pennsylvania and prepared envelope curves for the observed range of natural median-daily temperatures in four physiographic settings and for various ranges in altitude. These envelope curves can be used to estimate the annual distributions of median-daily temperatures for most thermally unaltered streams in Pennsylvania. Estimates should be within about 2°C in midsummer and within about 1°C in midwinter.

Highway embankment storage with culvert relief

From studies of various types of runoff events in Wyoming, G. S. Craig, Jr., found that single-peak events with high volume, occurring from high intensity rainfall, are critical in design involving embankment storage and culvert size. Compared with high-volume single-peak events, long-duration events and multipeak events of volume equal to the single-peak event do not cause as high a ponding elevation behind highway embankments with culvert relief. A model was used to determine the effect on inflow runoff hydrographs of a hypothetical wedge-shaped reservoir with a box-culvert outlet. Various sizes of reservoirs and culverts were considered in the analysis. The basic principle is that culvert discharge is a direct function of storage head.

CHEMICAL AND PHYSICAL CHARACTERISTICS OF WATER

Quality of ground water

A study of corrosion and encrustation in selected Alaskan ground-water supplies showed that some ground waters along the Alaska Peninsula are characterized by pH as high as 9.2, low hardness, no DO, and very low water temperatures. According to H. L. Heyward, because of the chemical character of these waters, corrosion is almost nonexistent in distribution systems and wells in the area. Some ground waters found along the Seward Peninsula are similarly characterized by high pH; however, the presence of DO along with a very low mineral content makes them very corrosive to distribution systems and water-handling equipment.

Ground water beneath recently irrigated fields in the Cedar Bluff Irrigation District in Kansas and return flow to the Smoky Hill River contain much more sodium and chloride than would be expected from the concentration and distribution of the ions in the applied water. Oil-field brine, which adversely affected some water supplies in and adjacent to the district, is the most obvious source of sodium and chloride. However, R. B. Leonard reported that chemical analyses of soil samples from adjacent irrigated fields were compared with analyses of soil samples from nonirrigated fields, and the results indicated that the principal sources of excess sodium and chloride are natural salts leached from the soil profile by the applied irrigation water.

L. A. Swain prepared a contour map showing the depth below sea level of the 250-mg/l line of equal chloride content of basal ground water on Oahu, Hawaii. The map shows that the greatest depths to this line occur where artesian water levels are the highest and where the confining beds are the most competent. In these areas, the column of water below sea level with a chloride content of 250 mg/l or less is about 40 times the height of the water level above sea level. In artesian areas where the confining beds are less competent, the fresh-water column below sea level is somewhat less than 40 times the water level above sea level. In heavily pumped areas and in large spring areas near the coast, the ground-water body generally has a chloride content exceeding 250 mg/l.

In areas where water-table conditions exist, the chloride concentration of the ground-water body generally exceeds 250 mg/l where the water levels are less than 2 ft above sea level.

The city of Modesto, Calif., is faced with water-quality problems. An investigation by R. W. Page indicated that (1) there is high nitrate content in water from some of the city wells and high nitrate content in the semiconfined water body that yields water to wells in and around Modesto, (2) a chloride-type water of moderate to high dissolved-solids content often occurs in the Tuolumne River which flows through the city, and (3) a saline water body containing a sodium-chloride-type water underlies the Modesto area at a depth of probably not more than 700 ft.

W. R. Moyle, Jr., reported temperature and chemical data for 95 thermal wells and springs in southern California. He points out some of the detrimental effects caused by water containing constituents with concentrations above those recommended for a particular use. A map was prepared to show the spatial relation of the wells and springs to large, known fault systems. Probably the most important result of the study was delineation of several previously unknown areas in which ground-water temperatures are much higher than normal for the surrounding area.

Water quality of streams

The use of 0.45-μm membrane filters for filtration of water is a common practice, but some fine clay can pass through the filters. When the purpose of an analysis is to determine only the major constituents of dissolved solids, the introduction of a small quantity of clay may not significantly affect results of the analysis. However, V. C. Kennedy, B. F. Jones, and G. W. Zellweger demonstrated, with analytical help from P. R. Barnett, that errors of 100 percent or more can be introduced into the analysis of aluminum, iron, manganese, and titanium dissolved in water when fine clay passes through the 0.45-μm filter. Such errors can occur either when making spectrographic analyses of water residues obtained by evaporation or when making analyses of water samples which were acidified after filtration. The acid dissolves aluminum, iron, manganese, and titanium from the suspended clays, and the concentrations present are greater than those in solution prior to acidification of the filtered sample.

Pore-water solutes

Jacob Rubin and R. V. James developed a new one-dimensional digital-computer model for predicting trace-solute transfer within a saturated porous medium. The model is applicable to media which are either homogeneous or layered and to solute transfers which may be affected by the following

processes: steady or transient convective flow; exchange reactions; film, surface, interaggregate or intraaggregate diffusion; and hydrodynamic dispersion. The model predicts transfer of a given solute by solving a set of simultaneous partial differential equations (one equation for the dissolved form and one for the adsorbed form of every chemical species particpating in the exchange reaction). A Galerkin-type numerical technique is used to obtain the result. This technique makes it possible to avoid the computational difficulties occurring when the commonly used finite-difference methods are applied to transport equations with convective and dispersion terms.

RELATION BETWEEN SURFACE WATER AND GROUND WATER

Use of ground-water maps in estimating low flows

Estimates of low-flow characteristics based on several years of base-flow measurements of streams in southeastern Massachusetts have been related by multiple regression methods to the drainage area and average transmissivity of the unconsolidated deposits underlying the area. J. R. Williams and G. D. Tasker found that streams draining areas with high infiltration capacity and ground-water storage exhibit higher low flows than streams draining less permeable areas. The resulting formulas allow estimates of the 7-day, 10-yr low flow of ungaged streams in southeastern Massachusetts from ground-water availability maps.

Flood-plain aquifer recharged from stream

Results of a study by H. H. Schumann (1972) and B. W. Thomsen indicated that the highly permeable stream alluvium underlying Tonto Creek and its flood plain is the principal aquifer in the lower Tonto Creek basin in central Arizona. The basin is drained by the south-flowing Tonto Creek, which discharges into Roosevelt Lake. Water levels in wells drilled in the stream alluvium rise quickly in direct response to floodflow in Tonto Creek, indicating that a large part of the flow enters the ground-water reservoir. The chemical composition of the base flow in Tonto Creek was found to be similar to that of the ground water pumped from the stream alluvium, thus providing additional evidence that the stream alluvium receives most of its recharge by infiltration from the creek.

Systems model indicates source of recharge

M. E. Broom and J. E. Reed reported that a preliminary analysis was made of the Bayou Bartholomew alluvial aquifer-stream system in southeast Arkansas with the use of an analog model. The analysis indicates that the largest source of recharge to the aquifer is by capture, caused by ground-water pumpage, from perennial streams in the area. In 1970, capture may have amounted to as much as 65 percent of the 186,000 acre-ft pumped from the alluvial aquifer. Although most perennial streams in the area are still seasonally acting as drains, the net effect of approximately 20 yr of ground-water pumping has been a depletion of the surface-water supply.

Return flow from irrigation

M. E. Broom reported that irrigation return flows were measured at five instrumented sites in the Bayou Bartholomew basin in southeast Arkansas. The sites reflect a variety of soil types, rates, and efficiencies of application. Return flows ranged from 11 to 33 percent of the applied irrigation waters. The average value, 25 percent, indicates that approximately 59,000 acre-ft is returned to streams in the area during the summer irrigation season.

Ground water is major element in water budget of lake

Ground water is an important source of water to Lake Wingra, a 339-acre shallow lake bounded by the Madison urban area and the University of Wisconsin Arboretum, Dane County, Wis. E. L. Oakes and E. E. Zuehls estimated that in water year 1971 the lake gained 39 in. from ground-water inflow. The lake received 30 in. of precipitation, and inflow from springs, creeks, and storm sewers was about 44 in. Evaporation from the lake surface was about 40 in., measured lake outflow was 78 in., and decline of lake storage was 5 in. An unknown amount of ground water may leave the lake as underflow beneath a sedge meadow at the east end of the lake or as downward movement induced by pumpage of deep aquifers; the 39 in. estimated for ground-water inflow to the lake is low by the amount of these possible drafts.

Ground-water contribution to flow of the South Platte River

Ground-water seepage to the South Platte River between Henderson and Julesburg, Colo., makes up approximately 39 percent of the total surface-water supply according to D. R. Minges and R. T. Hurr. A water-budget analysis for a 3-yr period indicated that the average yearly surface-water inflow into the South Platte River valley project area was 780,000 acre-ft whereas diversions and outflows totaled 1,280,000 acre-ft. The 500,000 acre-ft per yr difference, representing the net ground-water seepage to the river, was within 10 percent of the net seepage estimated from field measurements of river gain and loss.

Waste-water infiltration at the city of Mount Shasta

Reduced rates of infiltration and increased inflow are occurring at the waste disposal ponds of the city of Mount Shasta, Siskiyou County, Calif. Analyses, by G. L. Bertoldi, of data from test wells near the ponds led to discovery of (1) a perched water body that intersects the bottom of one of the

ponds, and (2) a cemented clastic sediment underlying another of the ponds. Field infiltration tests indicate that only one pond is effectively functioning and its capacity is about 0.15 to 0.17 mgd, which is about half the infiltration rate required to service a city the size of Mount Shasta. Biological clogging of the ponds probably is not significant.

River-water quality related to ground water

Results of a recently completed study by P. J. Horick (Iowa Geol. Survey) and W. L. Steinhilber (USGS) of the Mississippian carbonate aquifer, which underlies about 60 percent of Iowa, showed that the Des Moines River is a principal drain for water discharging from the aquifer. This ground-water discharge has a noticeable effect on the chemical quality of the river water in the lower reach of the stream. In that reach the sulfate content of the river water, which ranges between 30 and 85 mg/l during above-average to average flows, increased to about 145 mg/l at the 90-percent flow duration and to about 180 at the 99-percent flow duration. This increase is related directly to the high sulfate content (in excess of 2,000 mg/l) of the water in the Mississippian aquifer in the south-central part of the State.

SOIL MOISTURE

The principles of soil-moisture retention and movement are a vital link in the chain of hydrologic principles being studied in efforts to understand and control our environment. The mechanisms involved in infiltration, evaporation, transpiration, and movement of water to the water table are being investigated in the natural environment as well as in the laboratory.

Soil-moisture changes during snowmelt in the Black River basin, New York

In a study which was a part of the Terrestrial Water Balance Program of the International Field Year on the Great Lakes, W. N. Embree and E. C. Rhodehamel found that soil-moisture content in the Black River basin of New York remained virtually unchanged during the snowmelt period of 1971. A record-high snowfall occurred; water content of the snow averaged more than 15 in. A neutron moisture meter was used to study the unsaturated zone. The ground-water table rose appreciably during the melt period but soil-moisture content increased only near the surface and just above the water table. Preliminary indications are that, except for temporary moisture accumulation above restricting strata, infiltration of moisture from snowmelt moves rapidly from the surface to the water table.

Unsaturated flow characteristics at recharge basins

Quantitative records of unsaturated flow patterns associated with known inputs are being obtained by R. C. Prill at seven recharge basins on Long Island, N.Y. These records serve as the basis for assessing the ability to predict flow patterns using the current theory of unsaturated flow.

Test data show the critical parameters for prediction modeling to be the geometry and the saturated hydraulic conductivity of fine-textured strata. The geometry generally can be delineated effectively with the aid of neutron-moisture logs, natural-gamma logs, and core samples. Accurate prediction of the saturated hydraulic conductivity of the fine-textured zones is more difficult because of considerable variation in both horizontal and vertical directions. Air-permeability techniques for determining hydraulic conductivity represent a larger sphere of influence than laboratory testing of core samples and, when these techniques are employed, fewer tests are needed. The values of hydraulic conductivity obtained with the air-permeability technique are markedly lower than values obtained from ponding test data. These low values appear to be related to insufficient drainage of the strata.

Approximation of soil-moisture retention

R. F. Miller and I. S. McQueen find that standard filter papers, calibrated for determining moisture sorption forces in samples of soil obtained from the field, also provide a standard of comparison for defining moisture retention capabilities of soils. Sorption forces are determined from the moisture content of filter papers at equilibrium with the moisture in each sample of soil. The ratio of moisture in samples of soil, as compared to paper standard, tends to remain constant over a wide range of sorption forces. This permits use of the ratio to approximate moisture retention capabilities.

Results indicate that there is a linear relationship between the ratio used to define moisture-retention capabilities of soils and their moisture content at saturation. This permits an approximation of moisture-retention capabilities of soils which range from field capacity to dryness. If necessary, soil samples can be saturated and their moisture content determined in the field.

Hydrologic effects of changes in vegetation cover

Precipitation, runoff, sediment yield, and soil moisture were measured in four watersheds near Wolcott, Colo., from 1965 to 1967. In 1967, big sagebrush (*Artemisia tridentata*) that covered all four watersheds was killed by plowing in two of the watersheds, and the areas were reseeded to bluebunch wheatgrass (*Agropyron inerme*). Measurements of the same variables were continued in all four watersheds through 1970. As a result of these studies, G. C. Lusby and L. M. Shown found that, during the last 2 yr of study, runoff from rainfall on the grassed areas was reduced by about 60 percent and sediment yield from these areas was reduced by about 80 percent. During the same period the ground cover of live plants plus

mulch was about 40 percent greater on the grassed watersheds than on the sagebrush watersheds.

From soil moisture measurements it is concluded that, although grass and sagebrush use about the same amount of water, grass uses moisture more efficiently because of the greater amount of cover and forage produced.

Simulation of waterflow in the unsaturated zone

Jacob Rubin adapted a numerical method of the Galerkin type to simulate waterflow in the unsaturated zone. The relevant parametric functions were described by fitted algebraic equations containing only polynomial or exponential terms. This description made it possible to shorten considerably the computation time required for a given simulation. For the cases tested, such a simulation proved to be significantly faster than the ones based on the commonly used, implicit, finite-difference techniques of comparable accuracy.

Measuring hydraulic conductivity of unsaturated porous media

C. D. Ripple and Jacob Rubin developed a new quasi-steady method for measuring the hydraulic-conductivity function of unsaturated porous media in the laboratory. The method utilizes an apparatus consisting of a vertical infiltration column, an accurate infusion pump, and a pressure transducer. The apparatus developed makes it possible to attain steady flow conditions in the column's uppermost layer and to determine the pressure head and hydraulic conductivity characterizing this layer. By choosing a series of appropriate infusion rates, information about the dependence of hydraulic conductivity on pressure head can be obtained. The new method is considerably faster than older techniques of comparable accuracy.

EVAPOTRANSPIRATION

Evapotranspiration consists of the conversion of liquid water to vapor and mixing of water vapor at the earth-atmosphere boundary. It is the sum of water transpired by plants and evaporation of water from the soil, water, snow, plants, and artificial surfaces. Evapotranspiration accounts for approximately 70 percent of the 30-in. average annual precipitation in the conterminous United States, for nearly all the precipitation in the arid regions, and for approximately one-third of the precipitation in the more humid regions. Thus it is a significant component of the hydrologic cycle.

The rate and quantity of evapotranspiration is primarily determined by the availability of water and energy and by the rate of transport of water vapor from the evaporating surfaces.

Quantitative measurements of evapotranspiration are important for water-resource planning activities, such as prediction of available water supplies for various uses, estimation of drought incidence, and location of storage reservoirs and conveyance systems. Investigations of evapotranspiration by the USGS include studies of evaporation from lakes and reservoirs, evapotranspiration from vegetated land surfaces, and consumptive use of water by phreatophytes.

Evaporation studies at Lake Hefner, Oklahoma

Meteorological data gathered for a 15-month period at Lake Hefner, near Oklahoma City, Okla., were analyzed by H. E. Jobson to determine the effect that averaging windspeed and temperature for time periods of various lengths would have on computed values for evaporation. The effect of using the averaged data in computing evaporation was determined for time periods of 3 hr, 1 day, and 1 month. The results showed that the value of the semiempirical mass-transfer coefficient, N, is independent of the length of the time period over which the data was averaged if the period is not longer than 1 day. The error caused by averaging the data was larger than ±5 percent for 3 percent of the 3-hr averages and 20 percent of the 1-day averages.

Evapotranspiration loss in southern Florida

Data prepared by J. T. Armbruster and Howard Klein, from inflow-outflow studies for the three combined water conservation areas of the Central and Southern Florida Flood Control District, showed that from April 1, 1970, to March 31, 1971, evapotranspiration exceeded rainfall by about 30 percent. During this period of prolonged drought, rainfall was 40.5 in. and evapotranspiration was 52.5 in. In May 1971, at the end of the drought period, water was pumped from Lake Okeechobee, where the water level was approaching the record low, to the major well fields of Miami and Fort Lauderdale.

Transpiration resistance of saltcedar

T. E. A. van Hylckama reported that meteorological data, obtained during a series of 72-hr observation periods at phreatophyte sites near Buckeye, Ariz., showed that saltcedar (*Tamarix pentandra*) rarely uses water at the potential rate of evapotranspiration. When potential evapotranspiration increases (during periods of high windspeed and high temperature), actual water use by saltcedar may decrease. The reduction in water-use rate by saltcedar is attributed to aerodynamic and stomatal resistance to water-vapor diffusion, which may reduce water use by 30 percent of the potential evapotranspiration rate and is dependent on environmental factors including salinity of the soil moisture.

LIMNOLOGY

Water quality of impoundments

Results of a study by D. A. Goolsby and B. F. McPherson show that the Taylor Creek impoundment, located 15 mi west of Cocoa, Fla., exhibits strong chemical and thermal stratifica-

tion throughout much of the year. Water in the impoundment, 30 ft deep in some areas, is usually anaerobic below a depth of about 8 ft except during late fall and winter. Orthophosphate content, in terms of equivalent elemental phosphorus, often exceeds 0.5 mg/l, and ammonia content, in terms of equivalent elemental nitrogen, often exceeds 2 mg/l in the anaerobic layer, more than 10 times than observed in the aerobic layer. Values of Eh change sharply from 400 to 500 mv positive to small negative values just below the point where oxygen reaches "analytical" zero. Hydrogen sulfide and high concentrations of dissolved iron are also present in the anaerobic zone.

The dominant benthic organism in the anaerobic zone, larva of the phantom midge (*Chaoborus* sp.), often exceeds 10,000 individuals/m^2. A wider variety of benthic organisms is present in shallow-water areas where bottom waters remain aerobic, but the organisms are fewer in number. Plankton blooms have not been observed, but large areas of the impoundment are often covered with duckweed (*Lemna* sp.) and water-hyacinth (*Eichhornia crassipes*).

Lopez Reservoir in San Luis Obispo County, Calif., is a new (1969) but enriched body of water. Data collected by R. C. Averett and W. G. Hines in a study of the impoundment indicate strong thermal stratification of the water except for a brief period in winter. Algal cell counts of surface-water samples commonly exceed 100,000 cells per liter. However, during bloom conditions the count may exceed 500,000 cells per liter. *Stephanodiscus* sp. and *Fragillaria* sp. are commonly associated with the bloom conditions.

In their investigation of the thermal characteristics of the Flaming Gorge Reservoir on the Green River in Utah and Wyoming, E. L. Bolke and K. M. Waddell determined that the position of the hypolimnion in the impoundment remained virtually unchanged during the initial 1-yr period of the reservoir's existence. Water temperature is near 4°C from the top to the bottom of the hypolimnion, and the DO concentration is near zero throughout the deep zone—conditions which are also virtually the same as those established initially. However, some change was noted in the average monthly temperature of the Green River near Greendale, Utah, downstream from the reservoir. Before closure of the reservoir the average monthly temperature of the river ranged from 0° to 20°C; after closure it ranged from 4° to 11°C.

Hydrology of Lake Thonotosassa, Florida

Lake Thonotosassa is a shallow, 824-acre lake in eastern Hillsborough County, Fla. The surface altitude of the lake coincides with the water table in the shallow sand aquifer and is about 10 ft higher than the water surface in nearby tightly cased wells which penetrate the limestone (Floridan) aquifer beneath. The 14-ft-deep lake is underlain with a deposit of relatively impermeable sand and clay. Nutrient-rich deposits cover part of the lake bottom where the water is more than 10 ft deep.

R. C. Reichenbaugh and J. D. Hunn attributed oxygen depletion in the shallow lake to the decomposition of the incoming load of inadequately treated domestic and industrial (food-processing plants) wastes prior to 1970 and to occasional algal blooms in the enriched lake. After Plant City began operation of a new modified-activated-sludge waste treatment plant in 1970, BOD reduction was about 98 percent, and some reduction in total nitrogen and phosphorus loads occurred. However, nutrient-rich deposits in the lake and incoming nutrients may contribute to future algal blooms.

Association of bacteria with blue-green algae

In a study of symbiotic relationships between blue-green algae and bacteria, P. E. Greeson and T. A. Ehlke reported that the bacterial floras of the blue-green algal species *Gloeotrichia echinulata*, *Microcystis aeruginosa*, *Anabaena flos-aquae*, and *Anabaena spiroides* consist of the genera *Pseudomonas*, *Archromobacter*, *Flavobacterium*, *Alcaligenes*, and *Acinetobacter*. The flora of anyone of these algal species consisted of as few as two to as many as five genera of bacteria. The bacterial flora of the algae were similar in two respects: (1) The bacteria were gram negative rods, and (2) the bacterial flora of a given algal species was virtually the same regardless of the type of culture medium.

A bacteria-free (axenic) culture of *Microcystis aeruginosa* was obtained by a combination of ultraviolet radiation, ultrasonic vibration, and mechanical manipulation.

Limnology of arctic streams

Water quality and aquatic biology were studied in a small drainage basin on the south side of Brooks Range, Alaska, during August 1971. Five stations were sampled from the headwaters at about 5,000 ft altitude (a first-order stream) to the mainstem of Dietrich River at about 1,800 ft altitude (a fifth-order stream). Stream width ranged from about 5 ft to 49 ft from the headwaters to the fifth-order stream. At the first-order station, where flow originated from seepage and snowmelt, the streambed was covered with attached algae. The algal growth on the streambed decreased from low-order to high-order streams.

J. W. Nauman and K. V. Slack found that water temperature and the concentration of dissolved solids increased downstream from the headwaters as did specific conductance (from 120 μmhos/cm^2 at 25°C in the first-order stream to 420 μmhos/cm^2 at 25°C in the fifth-order stream) and that the relative proportion of dissolved sulfate and carbonate decreased in the downstream direction. Nitrate nitrogen was present throughout but organic nitrogen at the headward three stations was replaced by ammonia nitrogen at the lower stations. Phosphate and nitrite were not detected in any of the streams.

It was determined that the diversity of benthic invertebrates collected from the streams increased with stream order from a

low at the headwaters (8 taxa, diversity index $\bar{d}$=1.11) to a high at the fifth-order station (10 taxa, $\bar{d}$=2.17). However, the maximum number of taxa occurred at the third- and fourth-order stations, 14 and 12, respectively. These diversity values are significantly lower than would be expected for unpolluted streams in temperate areas, which is an indication that the natural environment may severely limit the diversity of aquatic communities in these streams.

Trophic conditions of west coast lakes

The present trophic status of 23 lakes in western and eastern Washington was investigated by G. C. Bortleson, G. T. Higgins, and G. W. Hill. The potential for nutrient enrichment from cultural and natural sources was evaluated on the basis of the interaction of several physical and hydrologic factors that play a role in controlling the trophic condition of lakes, such as mean depth, altitude, ratio of volume of water to number of nearshore homes, mean temperature in the photic zone, and the rate of water replenishment. The actual trophic conditions of the lakes studied were evaluated separately, on the basis of several indicators of nutrient enrichment (rate and duration of DO depletion in the hypolimnion, chlorophyll *a* levels, seasonal phosphorus and nitrogen concentration, changes in specific-conductance profiles, occurrence of algal blooms, macrophyte abundance, and water transparency).

Harts Lake, a natural eutrophic lake in the Puget Sound lowlands of Washington, is a circular kettle lake (maximum depth is 50 ft) lying between till hills of recessional outwash and stratified drift. The 121-acre lake, which was studied by Bortleson, Higgins, and Hill, is situated in a moderately forested basin with some residential and agricultural clearing. Six residences (three are seasonal) and a resort occupy about 10 percent of the shoreline. Thus, a relatively large volume of water compared to the number of lakeshore homes (477 acre-ft per home) would tend to minimize nutrient enrichment from nearby residential sources. The water is replaced approximately every 2 yr. At winter mixing, it is characterized by specific conductance of 129 μmhos/cm^2 at 25°C, bicarbonate of 62 mg/l, and color of 50 Pt-Co (platinum-cobalt) units. The rooted aquatic-plant and phytoplankton growth is profuse, and frequent algal blooms occur. Chlorophyll *a* determinations ranged from 9.2 to 48 μg/l during the spring and summer of 1971. Secchi disk visibility ranged from 3.0 to 11.0 ft.

DO was depleted in the hypolimnion during summer stratification resulting in an average of 54 percent of the lake volume having less than 4.0 mg/l DO from May 13 to September 13, 1971. Intense supersaturation of DO (166 percent at 5 ft below the water surface) occurred in the photic zone on July 1 during a bloom primarily composed of *Anabaena* sp., *Aphanizomenon* sp., and *Ceratium* sp. Organic phosphorus and nitrogen concentrations sampled 3 ft below the water surface, were relatively high compared to those in other lakes in the Puget Sound lowlands with ranges of 0.01 to 0.17 mg/l orthophosphate phosphorus, 0.03 to 0.20 mg/l total phosphorus, 0.07 to 0.64 mg/l ammonia nitrogen, and 0.01 to 1.2 mg/l nitrate nitrogen.

Despite only limited cultural influence, the lake is highly productive which may possibly be attributed to the availability of nutrients from sediments in the littoral zone and bottom as well as to the supply of organic material from peat and muck drainage.

A midsummer survey of 20 California lakes by R. T. Iwatsubo, L. J. Britton, and R. C. Averett revealed a wide variety of water types. The lakes, mostly in northern California, ranged from the unenriched waters of the Sierra Nevada to the enriched basins in the Central Valley and northeast prairie region of the State. Most of the lakes were thermally stratified with well-developed metalimnions. DO profiles varied widely between the lakes. Three lakes had complete metalimnetic oxygen depletion, whereas others had oxygen throughout the water column with minimums near the sediment-water interface.

PLANT ECOLOGY

Cause of vegetation differences on opposing slopes

An intensively instrumented study of a wooded area in northern Fairfax County, Va., is being made by R. L. Phipps and C. P. Baker to relate variations in soil moisture and ground-water levels with plant distribution. They expected to show asymmetrical moisture distribution on opposing slopes as the probable cause for the striking differences of the vegetation on the two slopes. However, preliminary findings by Baker indicated little difference in the moisture regimes of the opposing slopes. No significant difference in soil moisture between areas was noted for periods when seeds germinate and seedlings become established. At one site, plant distribution may be affected by seedling death caused by extreme temperature fluctuations which may range from below freezing to above 100°F in less than 6 hr.

Factors causing trees to lean on slopes

Previous investigations indicated that trees typically lean downslope and that this common leaning is not the result of soil or slope movement. Recent evidence collected by R. L. Phipps, as part of a study of anomalies in tree form and tree-ring patterns, indicates that degree of leaning is a function of shade tolerance of the tree species as well as slope steepness but may be independent of slope exposure. Shade-intolerant species (oak and hickory) were found to lean more than shade-tolerant species (beech) which may not lean at all. Oak grows more on the upslope side of the tree trunk, whereas beech appears to grow more on the south-facing side of the tree regardless of slope exposure. Greater growth on the upslope side of oak is suggested to be the result rather than the cause of tree leaning.

Vegetation measurements for hydrologic purposes

Preliminary analyses by F. A. Branson show that amounts of aerial plant cover relate more directly to annual runoff and to runoff as affected by conversion of pinyon-juniper woodland to grassland than other parameters of vegetation measured on the Fort Apache Indian Reservation, Ariz. Other kinds of vegetation measurements on the two experimental watersheds during the period 1958–71 include (1) foliage volumes computed from foliage depth and intercept measurements, (2) basal-point contacts on vegetation, mulch, rock, and bare soil, (3) numbers, basal diameters, and heights of trees, and (4) shrub numbers per unit of area. An inverse relationship was found between runoff and the marked decrease in aerial plant cover during the year of treatment. As aerial cover became greater on the grassland watershed than on the woodland watershed, runoff from the woodland watershed exceeded that of the grassland watershed. Computed foliage volume on the woodland watershed remained considerably greater than that of the grassland watershed. These results indicate that, if remote sensing methods can be developed which measure foliage cover of both woody and herbaceous species, these methods may be useful for determining intraregional variations in runoff that are caused by differences in aerial foliage cover.

Old maps document changes in riparian vegetation

During the past half century, vegetation changes along one short reach of the Gila River valley, Arizona, have not followed the pattern typical of earlier changes. The vegetation of this area on the San Carlos Apache Indian Reservation has been mapped four times since 1914. By comparing vegetation maps and by examining old photographs and journals, R. M. Turner (1972) has reconstructed past vegetation patterns. Forests of cottonwoods and willows; thickets of seepwillow, arrowweed, and seepweed; and woodlands of mesquite formerly alternated in a complex pattern along the valley. Even though these groupings were in some places altered by floods, by deposition, or by inundation, such changes fell within well-defined limits. Today, however, the flood-plain sites are dominated by a single introduced plant, saltcedar. The heterogeneity of the past has given way to the present uniform condition.

Within the area susceptible to flooding by the San Carlos Reservoir, the establishment of saltcedar is probably directly related to the presence of the impounded water. Upstream, outside of the area of the reservoir's influence, the most rapid invasion by saltcedar occurred at least 20 yr ago after large floods had removed most of the original vegetation and after native phreatophytes had already regained occupancy of the old flood plain. Saltcedar has eliminated the native vegetation and there are indications that this exotic plant is capable of maintaining indefinitely its hold on the invaded areas.

NEW HYDROLOGIC INSTRUMENTS AND TECHNIQUES

MISCELLANEOUS INSTRUMENTS AND TECHNIQUES IN WATER-RESOURCES STUDIES

G. F. Smoot reported the development of an automated bathymetric profiling system capable of surveying estuarine geometry quickly, at low cost, and with a high degree of coverage. The boat-mounted system includes a ranging device, a depth sounder, a digital tape recorder, a precision clock, and a digital logic package to control the system operation. Components are compactly packaged and can be easily transported, and the system can be operated from a small boat. Shore-based water-level stations, synchronized with the boat system, provide the data necessary for the tide-correction adjustments. The standard boat record includes time, two ranges, and a depth. Three auxiliary channels are available for reporting salinity, temperature, or other parameters. The data is processed into profile charts through the use of a computer contouring program.

The bathymetric profiler meets a very critical need by providing an automatic data-acquisition system capable of collecting and processing the voluminous and detailed data needed for many estuarine investigations. Two surveys were successfully completed, using the system, and no major difficulties were encountered.

H. O. Wires reported that instrumentation is being developed to provide a better method of achieving continuous measurement of discharge through control structures. Research is being conducted on a shaft digitizer and a digital recorder to establish an all-digital data-handling system for this as well as other systems. Wires also reported that data platforms for the ERTS satellite program relay network have been finalized and will be tested for operational suitability in the near future. Some interface and peripheral devices were developed or are in the planning stage.

W. S. Keys and R. F. Brown used a high-resolution temperature probe to trace the movement of recharge water through the Ogallala Formation in Texas. The diurnal temperature fluctuation of recharge water from a playa lake was detected at a distance of 150 ft from the injection well. Changes in ground-water velocity were plotted as a function of time, distance, and depth. Although the aquifer at one site is a uniformly fine sand with very consistent size distribution and porosity, significant differences in flow rate with depth were found by temperature tracing. Natural gamma spectra run in boreholes in the Ogallala correspond closely with radiometric analyses of core and the calcium carbonate content of samples. In situ gamma spectra are being compared with temperature and other logs related to the permeability of the aquifer.

Keys and Brown reported that a new double-detector brine

ejector was developed and successfully tested. The system provides positive identification of flow direction and is sensitive to very low velocity flow. They also reported that a gamma-gamma core scanner was built and is now being used to examine cores in sample tubes prior to selection of intervals for laboratory analyses. Disturbed core and voids in the core are readily detected by this method.

George Landers developed an automatic, programmable moisture logger. The system turns on, logs the hole, and shuts off at preselected time intervals. It is being used at a recharge site in the Ogallala Formation in Texas to monitor changes in moisture content caused by the downward migration of water spread on the surface.

J. E. Eddy reported that a commercial depth-sounding unit was modified so that it could be used for inspection of cavities tapped by wells in the Huntsville, Ala., area. A transceiver unit was lowered on pipe into a well. This arrangement permitted accurate depth readings to be made and also allowed for proper orientation of the device so that the shapes and trends of the cavities could be determined. This device can also be combined as a unit with both a flowmeter and television camera for comprehensive well surveys.

Comparison of radiation values obtained from the X-3 insulated pan, developed by the U.S. Weather Bureau, with those obtained using standard radiation instruments showed very good correlation, according to A. M. Sturrock, Jr. Sturrock also reported that a recently developed direct-current motorized psychrometer has been tested against a thermocouple psychrometer. The results of the comparison were excellent, and the direct-current motorized psychrometer is now considered to be fully operational. Both instruments have the capability of gathering accurate data in remote areas where alternating-current power is generally not available.

G. E. Ghering and H. A. Moore conducted extensive tests, both in the laboratory and in the field, on a temperature-compensated flat-plate radiometer. An analysis of the results indicated instrument performance to be unsatisfactory, primarily because of drift problems. Replacement of the direct-current power supply to the temperature-compensation unit by an alternating-current supply is under consideration as a possible solution to the problem.

Samplers used for obtaining suspended sediment contain moderate to large concentrations of copper, lead, and zinc which contaminate the water samples collected during trace-element investigations. V. C. Kennedy and J. V. Skinner modified the DH-59 suspended-sediment sampler to greatly reduce the problem by coating the surface of the sampler with epoxy paint, replacing the regular rubber gasket with silicone rubber, and replacing the metal nozzles with teflon.

J. V. Skinner and J. P. Beverage reported that a large volume point- and depth-integrating sampler designed for use in estuaries has been completed and will be reviewed by interested federal agencies. Also, an experimental sediment detecting system that contains a sensitive hydrophone has been built and is now being tested. Skinner and Beverage have completed plans for the PS-69 automatic pump sampler, and all future units can now be manufactured under contract. They also report that the proportional frequency controller, which converts a pumping sampler to a discharge proportional device, was modified to reduce standby power requirements and to increase the level of noise immunity.

J. P. Bennett reported that a suspended-sediment sampler which is capable of pumping water-sediment samples at stream velocity has been designed and built. The main advantage of the pumping sampler over existing suspended-sediment samplers such as the US-P series samplers is that a sample of any desired volume can be collected without changing the position of the sampler. The sampler uses a pump-through pitot tube as a combination velocity sensor and sampler nozzle. The sampler nozzle has an expansion chamber just inside the inlet to compensate for head losses in flow from the inlet to interior pressure taps. The pump speed is controlled by a feedback loop which has as input a voltage proportional to the pressure difference between the interior and an exterior pressure tap. Samples collected with the pumping sampler could not be distinguished from those collected with a modified US DH-48 or a siphon sampler.

F. A. Swenson developed equipment which is capable of logging the pH, Eh, and specific ion activity of fluids in situ in boreholes and which is undergoing field testing and calibration. Swenson and C. G. Bowles obtained significant results in logging to depths of almost 1,000 ft in uranium test holes on the flanks of the Black Hills. Good results also were obtained in logging in water wells to a depth of 850 ft in the San Antonio, Tex., area. Relationships between the pH, Eh, and sulfide-ion activity are evident. The equipment, when fully tested and calibrated, will provide information which will be useful in geochemical interpretations, encrustation and corrosion problems, recharge and underground waste-storage studies, environmental pollution studies of lakes and waterways, and mineral-deposit exploration.

The strain-gage flowmeter has been found to be the fastest and most accurate device tested for measuring flow through the large-diameter irrigation pipes in southwestern Louisiana, according to A. L. Zack. The meter works on a cantilever principle—the force of flowing water on a fixed-end target is translated into an electrical output, which is proportional to the square of the flow rate. The meter is attached (by a union) to a closed corporation cock welded to the intake or discharge pipe. It is lowered through the opened cock and into the pipe; velocity measurements are then made at various points and plotted as a velocity profile. From this profile a value of average velocity can be determined. With this average velocity applied to the area of the pipe, the rate of flow can be determined. Where both the flow through the pipe and the flow in a flume (using a current meter) were measured, the accuracy of the strain-gage flow measurement was verified. The strain-gage flowmeter used in this study is a mobile adaptation of a similar, stationary, commercially manufactured model.

G. W. Edelen, Jr., is investigating the feasibility of using airborne instruments and techniques for accurately sensing ground profiles. Accuracies of ±0.5 ft are needed for computing water-surface profiles by step-backwater procedures.

Previous investigations by Coyd Yost, Jr., indicated that airborne methods with the greatest potential for measuring ground-surface elevations to the required accuracy are (1) laser altimetry, which utilizes a laser to measure the distance to the ground below an airplane and an accelerometer or barometer to measure the vertical position and movement of the airplane and (2) photogrammetry. Accuracies of ±1 ft were indicated in preliminary field tests of the laser-barometer method.

COMPUTER TECHNOLOGY IN WATER-RESOURCES STUDIES

Digital computers are now used routinely by most researchers in water-resources studies. Only current highlights are indicated below.

Finite-difference techniques make it possible to approximate and to directly solve partial differential equations. In water-resource studies, a number of partial differential equations which describe the following phenomena or activities are of interest: (1) The unsteady flow of water in a stream channel, (2) the unsteady flow of ground water in an aquifer, (3) the unsteady transport of chemical constituents in either a ground-water or surface-water system, and (4) water-resources management.

Flow of surface and ground water

Several applications can be made of the data obtained during dye-tracing investigations. To aid in the conversion of the raw data into other forms, H. L. Shindel and B. H. Lowell developed a computer program in which raw data are the input. Computer-input cards are punched directly from the field-data sheets, which also contain, for this program, the coordinates defining the dye-dispersion curve. The output includes time of travel of the leading edge, peak, centroid, and trailing edge, as well as velocities for the leading edge, peak, and centroid. It also includes area under the dispersion curve, variance of the curve, variance with distance, dispersion coefficient, percent dye recovered, peak concentrations adjusted for percent recovery, amount of dye injected, and water discharge in the channel. If the mean width is included in the input data, the output will give the mean cross-sectional area, mean depth, and mechanical reaeration coefficients to base e and base 10.

W. D. Nichols reported that a digital-computer program for aquifer simulation was developed and tested as part of the geohydrologic investigation of the Englishtown Formation in New Jersey. The program is based on programs and subprograms written and developed by J. D. Bredehoeft and G. F. Pinder. The program developed during the present study can be used to simulate the response of a confined nonhomogeneous aquifer with irregular geometry. Transient and steady leakage from one or two adjacent confining layers may be included. The period of simulation may be subdivided into as many as 10 periods of pumping with different pumping rates and locations.

D. J. Lystrom reported that in order to benefit interagency planning of an automated (real-time) hydrometeorological data-acquisition network in the Pacific Northwest, the Northwest Water Resources Data Center investigated the potential accuracy of stream-discharge information that would be acquired. In comparison with historical records collected and processed by conventional methods, it was found that real-time information is potentially less accurate, primarily because there would be no opportunity for after-the-fact analysis and correction. Large errors, however, can be detected, and possibly corrected, by computerized methods utilizing statistical probability, correlation, and routing techniques.

Unsteady flows of many surface-water bodies cannot be simulated satisfactorily by one-dimensional digital models and must depend on two- or three-dimensional (space) approach. Chintu Lai has constructed a two-dimensional digital simulation model for unsteady flows in wide estuaries and embayments. The model employs the method of characteristics which is the extension of a one-dimensional characteristic method that he used previously. The model is applicable to unsteady flows of homogeneous-density shallow water having variables of about the same order of magnitude in both x- and y-directions on the x-y plane. Boundaries are either shoreline or open water; for the latter, water-surface elevation along the boundary points must be known. The program is capable of handling the Coriolis effect, the wind effect, and complex bathymetry. The method of characteristics for two-dimensional flow is far more difficult than that for one-dimensional flow in numerical scheme, algorithm, and programing. Unlike the one-dimensional model, this model was numerically unstable in the original form, and some remedy had to be taken. It was found that a stability could be obtained by suppressing high frequencies using a smoothing-effect procedure. Other ways of achieving stability are under investigation.

The initial time-step for a model simulation of ground-water flow is not critical in obtaining a solution, according to R. T. Hurr. Analyses of model results obtained by the finite-element method indicate that after 1 log-cycle of time, using 5 time-steps per log-cycle of time, the calculated head values are within 0.001 to 0.01 ft of the values obtained when using an initial time-step six orders of magnitude smaller. Thus, when using a digital model to estimate long-term effects in a ground-water system, a substantial savings in computer time and costs can be made by using a large initial time-step without any appreciable loss in accuracy.

Movement of chemical constituents in water

A digital-computer program developed by D. V. Maddy and

J. M. McNellis predicts the concentration and load of various chemical constituents. Regression techniques are used on chemical analyses of nondaily water samples with specific conductance as the independent variable and various chemical constituents as the dependent variable. The regression coefficients are then applied to daily conductivities to compute daily values for individual constituents. Program output can include daily concentration in milligrams per liter and tons per day, and 5-day cumulative and yearly totals of load in tons per day.

A one-dimensional digital model that involves the transport and reaction of ions most commonly found in ground water was formulated by D. B. Grove and was substantiated by laboratory experiments. The chemical-reaction part of the model assumes equilibrium conditions (reactions occur instantaneously) with the following chemical reactions being considered: (1) The ion exchange of sodium, calcium, and magnesium, (2) the precipitation or dissolution of gypsum, (3) the formation of calcium and magnesium ion pairs, and (4) five important carbonate reactions. The transport part of the model was formulated by incorporating finite differences and the Galerkin technique.

Rainfall-runoff relations

R. W. Lichty developed a versatile rainfall-runoff model to be applied to urban-area flood problems. Inclusion of snowmelt processes in rainfall-runoff models is being undertaken by P. H. Carrigan, Jr. Attention has been given to computer-program documentation of previously developed models.

Application of the law of conservation of mass to an aquatic system results in a set of simultaneous partial differential equations. S. M. Zand investigated the numerical solution of the set by using finite-differences and the Galerkin technique under various forms of source and sink functions and different boundary and initial conditions. A set of four simultaneous partial differential equations that can be adapted to represent an idealized nitrogen cycle in streams was solved numerically. The capability of the functional series representation of systems as a predictive tool in nonlinear hydrologic systems also was tested. This generalized nonlinear approach was investigated as a technique in modeling and simulation of surface-water quality.

Water-resources management

A digital model has been developed for the management of the water resources of the Arkansas River valley stream-aquifer system, according to O. J. Taylor and R. R. Luckey. The model simulates streamflow, ground-water storage, water delivery by canals and wells, water rights, consumptive use, reservoir operation, precipitation, and phreatophyte losses. Interrelations are simulated to make results meaningful. The model was used to analyze various management plans for water delivery and the stream-aquifer system. Water delivery can be improved by utilization of imported water and an associated reservoir, conjunctive use of ground and surface water, use of alternate rules for reservoir operation, and salvage of water presently lost by phreatophytes. Simulation of 5 yr of operation indicated that an improved management plan could reduce shortages from 33 to 17 percent of demand. The maximum predicted change in ground-water storage was 140,000 acre-ft, a general water-table decline of 3 ft. It was concluded that the management alternatives for the stream-aquifer system can only be evaluated by consideration of various multiple interrelations.

SEA-ICE STUDIES

Investigators of the USGS have used a three-phase approach to the problem of sea-ice dynamics; namely, (1) remote sensing in polar regions, (2) participation in international expeditions to the Arctic Ocean, and (3) development of numerical models for ice-covered oceans.

Numerical models incorporating three alternative ice constitutive laws

W. J. Campbell and L. A. Rasmussen continued study of their steady-state numerical models for sea-ice dynamics in which the ice is assumed to flow under the action of four forces: air stress, water stress, Coriolis force, and the internal ice stress. Prandtl-type boundary layers are assumed at both ice surfaces, with the water-boundary layer coupled to an ekman layer in which the vertical eddy viscosity is allowed to vary horizontally. Three different viscous ice constitutive laws are alternatively assumed for the internal ice stress: (1) Quasi-anisotropic, (2) isotropic with a variable shear viscosity depending on the sign of ice divergence, and (3) isotropic with constant shear and bulk viscosity. The equations are solved using an iterative technique for the same air-stress field for each choice of constitutive law, with two ice parameters in each case: (1) A shear viscosity for compression at a point and a shear viscosity for tension at a point, (2) a shear viscosity for areas of ice convergence and one for areas of ice divergence, and (3) a shear and bulk viscosity which are constant over the whole area.

For reasonable choices of these parameters it was found that (1) all three models gave smaller values of ice convergence in the anticyclonic gyre (Beaufort Sea) than those obtained in the earlier uniform ice-viscosity model, (2) models 1 and 2 yielded similar values of ice convergence and divergence but showed many small-scale differences in the field of ice flow, especially in the areas under and around an atmospheric cyclone, and (3) model 3 gave the smallest values of ice convergence and divergence.

Time-dependent model for sea-ice dynamics

A time-dependent model for sea-ice flow is being developed,

according to W. J. Campbell. The new model incorporates a continuity equation for a mesoscale ice thickness. This continuity equation is coupled with a momentum equation in which the viscous coefficients from the internal ice-stress term are related dynamically to the time-dependent mesoscale ice thickness. In order to obtain initial solutions for this model, a series of air-stress driving fields is being generated for the Arctic Ocean for the case of a cyclone traversing the Beaufort Sea from west to east.

ANALYTICAL METHODS

ANALYTICAL CHEMISTRY

Determination of small quantities of antimony

A sensitive and rapid procedure for determining submicrogram amounts of antimony in rocks was developed by M. M. Schnepfe. After fusion of a sample and dissolution of the fused cake, stibine is evolved by reaction with zinc in the presence of cadmium sulfate and is collected in a separatory funnel containing mercuric chloride and hydrochloric acid. Antimony is determined spectrophotometrically at 550 nm after extraction of the rhodamine B complex with benzene. Approximately 0.5 ppm antimony can be determined in a 0.2 g sample. As with a similarly designed arsenic procedure, the simplicity of both the procedure and the apparatus suggests ready application to geochemical exploration studies.

Method for the coulometric determination of water in small samples

M. J. Cremer and H. N. Elsheimer (1972), in collaboration with E. E. Escher of DuPont Instruments, have perfected the application of a microcoulometric method to determine hydrogen in minerals. The method involves electrolysis of water in a P_2O_5 cell (Keidel) and measurement of the quantity of electricity required. The sample is fluxed with CuO-PbO-$PbCrO_4$ in a combustion tube, the hydrogen in acid gases is converted to water by $CaCO_3$, and free hydrogen and organics are oxidized on MnO-Ag_2O_2, held at 450°C. In some minerals, samples of 10 to 20 mg are sufficient to determine total water with accuracy comparable to that obtained with 700 mg samples by the Penfield method. Disadvantages are mostly those peculiar to the use of small samples—weighing difficulties, moisture absorption, and sampling problems.

Fluoride determination using ion-specific electrodes

D. R. Norton, J. M. Gardner, and Claude Huffman, Jr., have modified a procedure for the determination of fluoride based on the measurement of fluoride activity with a specific ion electrode. Their procedure is an extension of recent work by B. L. Ingram and Irving May (1971). The new procedure involves fusing a 25-mg sample with sodium hydroxide in a zirconium crucible, leaching with ammonium citrate solution, and determining fluoride on the leachate. Fluoride in samples can be determined down to 0.01 percent.

Determination of micro amounts of nickel

L. B. Jenkins has applied the dimethylglyoxime-chloroform extraction procedure to the determination of micro amounts of nickel. The organic solvent is stripped with dilute HCl, and the aqueous solution is aspirated into a flame. Using atomic absorption, nickel has been determined in the low parts per million range in chromitite samples.

Determination of total iodine and iodate in sea water and in various evaporites

Iodine in sea water and evaporites is determined spectrophotometrically by M. M. Schnepfe as the starch-iodine complex without prior separation or concentration of the iodine. In slightly alkaline solution, iodide is first oxidized to iodate with permanganate. Oxidized states of manganese are then destroyed selectively with ferrous iron in phosphate medium without affecting the iodate. After acidification, the iodate is reacted with added iodide in the presence of starch. The iodate content is determined by omitting the addition of permanganate. As little as 0.1 μg of iodine is determinable in the presence of 500 mg of chloride and 5 mg of bromine. The total iodine concentration in seven samples of sea water was found to range from 50±3 μg/l for a mid-Atlantic water to 84±6 μg/l for a Red Sea water with 50 to 100 percent present as the iodate.

Mercury determination by flameless atomic absorption

Claude Huffman, Jr., R. L. Rahill, V. E. Shaw, and D. R. Norton applied a flameless atomic absorption method to determine submicrogram quantities of mercury in geologic materials. Dissolution procedures were developed for coals, shales, rocks, and soils. After sample dissolution, mercury is reduced to the elemental state and aerated from solution onto a silver screen where it amalgamates. The silver screen is subsequently heated and the mercury vapor swept through an absorption cell where its concentration is measured. The procedure is free from interferences due to organic matter or other volatile constituents of the sample. Elements that are easily reducible, such as tellurium or gold, must be absent from the sample solution. The detection limit of the method is 2 ng of mercury which absorbs 1 percent of the incident signal (I_0).

Determination of niobium and vanadium in sphene and rutile

Continuing the development of methods for analysis of sphene and rutile, Robert Meyrowitz has reported procedures for vanadium and niobium. The vanadium is determined by

the phosphotungstate procedure after a sodium carbonate fusion and a sulfuric acid dissolution. Using a 5-mg sample, 0.05 percent V_2O_3 can be determined. Niobium is determined spectrophotometrically with 4-(2-pyridyl azo)-resorcinol, known as PAR. The sensitivity for Nb_2O_2 is 0.2 percent using a 5-mg sample.

Sampling errors investigated

Investigation of laboratory subsampling problems by Paul Switzer (Depts. of Statistics and Geology, Stanford Univ.) and J. C. Engels and C. O. Ingamells (USGS) (Engels and Ingamells, 1970; Ingamells and Switzer, 1972; Engels, 1971; Ingamells and others, 1972) has shown that there can be serious sources of error in the analysis of naturally occurring materials. In potassium-argon dating, the presence of 1 percent or less of impurity in some mineral samples may invalidate analytical data. For example: a 40 percent age-difference anomaly in a pyroxene was shown to be due to less than one part in a thousand of contaminating feldspar; a hornblende of potassium-argon age 171 m.y. showed 146 m.y. before purification; an amphibole contaminated with 1 percent of orthoclase showed a relative error of 16 percent. In trace-element analysis, samples ground to −200 mesh may yield erroneous results because of subsampling difficulties; for example, spectrographic data on a −200 mesh graywacke showed that results for Cr, Zr, Cu, La, and Sc were not definable using Gaussian statistics. Poisson statistics should be used when the element of interest in geochemical samples resides in low-frequency mineral grains.

The Poisson distribution predicts that determinative values will almost always be too low when the subsample weight is small or too few subsamples are taken. Ingamells and Switzer have developed the application of Poisson statistics to practical analytical situations and have proposed the use of laboratory sampling constants which relate expected error to subsample weight. If the sampling constant for a constituent of a sample is known, subsample weights necessary to yield required accuracy can quickly be calculated. It is important to distinguish between analytical error and subsampling error. Sometimes subsample weights may be chosen to yield optimum subsampling errors: calculations based on the coefficient of variation of a series of determinations may be used to discover the nature and the extent of sample contamination or impurity. Only if analytical and subsampling error are separable is this possible. Non-Gaussian statistics and their application to practical sampling problems have not been adequately investigated, and this work is a start toward removing the deficiency.

Extraction methods for bitumens compared

Comparison of methods for extraction of sulfur-free bitumen from recent sediments, including lagoonal carbonate muds and estuarine detrital muds, indicates that a mixed solvent, such as benzene-methanol (3:1, v/v) or toluene-methanol (3:1, v/v), removes 6 to 10 times more bitumen than a single solvent such as benzene or toluene, according to the laboratory studies of J. G. Palacas, A. A. Roberts, and A. H. Love. Preliminary studies indicate that bitumen extracts from carbonate muds in Florida Bay contain as much as 50 percent elemental sulfur. Consequently, to obtain meaningful measurements of bitumen and hydrocarbon fractions of bitumen, the elemental sulfur is removed by passing the extract through a copper amalgam column which converts the sulfur to insoluble copper sulfide.

X-RAY FLUORESCENCE

Computer program for oxidation states

A computer program for analyzing X-ray emission spectral data on the soft X-ray spectrometer has been completed by J. R. Lindsay and R. R. Larson for use in the determination of oxidation state. The program calibrates the spectrometer and determines the dispersion of the analyzing crystal, converts readings into wavelengths and energy, smooths the data using a five-point smoothing function, calculates and subtracts a linear background from the smoothed data, normalizes to the highest intensity, locates the exact position of all emission lines and calculates full width and half maximum, and locates exact energy boundaries. In addition, the spectrum is plotted (using a Calcomp Plotter) as a function of smoothed intensity versus energy, background corrected intensity versus energy, and normalized intensity versus energy. The program makes more quantitative the determination of small energy shifts that occur as the valence and coordination of an element change in a structure.

Determination of chlorine in silicate rocks

B. P. Fabbi and L. F. Espos (1972) reported the accurate determination of chlorine in silicate rocks. The ubiquity of chlorine presented a variety of difficulties to be overcome in the course of adaptation and acceptance of the X-ray fluorescence technique (XRF). Subjects investigated include: contamination of prepared pellets by chlorine in the atmosphere, magnesium perchlorate desiccants, HCl left on glass lenses used in preparing pellets, and chlorine contamination of binder material used in preparing pellets. Precision of the XRF determination averaged ±7 ppm Cl over the range 10 to 500 ppm Cl. The lower limit of detection for the method was found to be 6 ppm at the 2σ confidence level.

Determination of zirconium in silicate rocks

A quantitative X-ray fluorescence (XRF) technique has been used by B. P. Fabbi and L. F. Espos to determine zirconium in silicate rocks. The determination of zirconium by XRF is hampered by both iron absorption effects and spectral

interference from $Sr_{K\beta 1,1}$ on the analytical line of $Zr_{K\alpha 1,1}$. By correcting the net intensity of the zirconium signal for iron absorption and then subtracting the amount of signal due to strontium in the sample, zirconium can be satisfactorily determined in silicate rocks. Precision of the XRF determination averages ±12 ppm Zr in the range 10 to 650 ppm. The lower limit of detection for the method is 9 ppm at the 2σ confidence level.

Determination of silica-alumina ratios in clays prepared for electron microscopy

J. R. Lindsay and E. J. Dwornik developed a technique to measure the silica-alumina ratio on clay minerals prepared for electron microscopy. One ml of an aqueous suspension of the clay materials is placed on a 1 in. diameter polished disk of graphite and allowed to evaporate to dryness. Standards are prepared in the same way using finely powdered glasses as reference material. The glasses were chosen because they are sufficiently homogeneous and single phased that there is no segregation due to difference in settling rate. An aliquot of the suspension is taken for electron microscopy at the same time as the aliquot for XRF analysis. The amount of solid material deposited on the graphite disk is estimated to be less than 100 μg.

Effect of incident radiation on proportional counters

A study of the effect of the energy of incident radiation on dead time of proportional counters was made by J. R. Lindsay. The results indicate that historical dead-time correction procedures, previously developed for geiger counters and used unquestioned for proportional counters, are not even a good approximation for proportional counting. The data show conclusively that, contrary to popular belief, count rates above 8,000 counts/sec. are subject to serious dead-time problems. The study was necessary in relation to continuing experiments on spectral analysis where count rates of major element peaks are compared with weak satellite lines.

NEUTRON ACTIVATION

Substoichiometric isotope dilution technique for determining indium

A procedure for determining 0.01 to 0.1 μg indium in rocks by a substoichiometric isotope dilution technique was devised by L. P. Greenland and E. Y. Campbell. After HF-$HClO_4$ decomposition in the presence of In^{113m} tracer, indium is separated from other elements by HBr and acetylacetone extractions and is reacted with a substoichiometric amount of ethylenediamine tetraacetic acid (EDTA); the excess indium is separated by extracting the iodide. The specific activity of the In-EDTA complex is directly related to the concentration of indium in the original sample. Analyses of the eight USGS standard rocks are in good agreement with previous neutron activation determinations.

Mercury determination in rocks and soils

In a procedure developed by P. J. Aruscavage, the sample is irradiated in a thermal neutron flux of 2×10^{12} n/cm^2/sec for 4 to 16 hr and is then decomposed by fusion with sodium peroxide in the presence of carrier mercury. Mercury is then separated by distillation as the element, followed by precipitation of mercury(II) sulfide. After counting the 65-hr Hg^{197} isotope on a high resolution Ge(Li) planar detector, the samples are reirradiated and recounted to determine the chemical yield. Because of the possibility that mercury may be lost during the peroxide fusion, mercury was determined in a series of samples, first by instrumental neutron activation analysis and then by the radiochemical procedure. The agreement between these two determinations is evidence that radioactive mercury in the sample equilibrates with carrier mercury before any fractionation occurs. The 3σ detection limit for a 16-hr irradiation in a thermal neutron flux of 2×10^{12} n/cm^2/sec is 0.3 ppb.

Determination of tantalum

J. J. Rowe and L. J. Schwarz have determined tantalum nondestructively by instrumental activation analysis, using the high-energy Ge(Li) planar detector to measure the 67.5 kev gamma of Ta^{182}. It was possible to determine as little as 0.2 ppm Ta. Results for standard rocks correspond to reported figures by other methods. Samples were also analyzed using the 1221 kev gamma peak. Results with this method were consistent with those for the 67.5 kev peak. The low-energy peak is considerably more sensitive.

EMISSION SPECTROSCOPY

Determination of volatile elements using synthetic minerals as standards

R. E. Mays, Chris Heropoulos, and G. K. Czamanske have improved the reliability of the spectrographic determination of certain volatile elements such as cadmium in sulfide minerals by the use of laboratory-synthesized minerals as standards. The intensities of spectral lines of a volatile element are greater if the element is present in a mineral structure rather than as the oxide in a chemical mixture. Sulfide minerals, made to contain the minor elements in a predetermined definite concentration, were synthesized in the laboratory by using the pure elements in stoichiometric proportions. Determinations of the volatile elements based upon working curves prepared from these synthetic mineral standards agree well with results obtained by other independent methods of analysis.

The determination of the composition of native gold

A spectrochemical method was developed by A. L. Sutton, Jr., R. G. Havens, and C. L. Sainsbury for determining trace, minor, and major element distribution in native gold samples. The method is applicable over a wide range of particle sizes and a very large range of element concentration. The nuggets are cleaned by acid and ultrasonics, flattened to a thin plate, and scanned with a microscope for inclusions. Gold up to 10 mg in size can be used for the analysis. A sample is digested in acid, evaporated and burned in an arc, and compared with carefully prepared standards. A comparative study made between nuggets cleaned with acid to remove the oxide coatings and uncleaned nuggets revealed that many trace elements were actually in the coating. Analysis of uncleaned nuggets can therefore give false information of the trace element content of native gold. As elements found in the coating may be of interest, the analysis of the acid wash was incorporated into the method. To test the method, 100 splits of an Alaskan gold sample were analyzed. The results showed that of 31 elements looked for, mercury values alone are not acceptable. The variation between splits showed that more than one sample is necessary to give a complete evaluation of all elements to be found at one geologic location.

Computerized spectrographic analysis

A high-speed magnetic tape recording system has been developed for the complete spectrochemical analysis of samples, the spectra of which have been exposed on 20-in. photographic plates. The key instrumental feature is an exceptionally precise microphotometer designed by A. W. Helz and built by C. J. Massoni as additions to and modifications of a commercial measuring machine. One 20-in. plate has 40 spectra, each spectrum requiring about 90 sec to record at the rate of 1,000 transmittance readings per sec (one every 0.025 A). A computer program, devised by F. G. Walthall, has been prepared for the 416 lines which will be used to analyze silicates for 69 elements. The program identifies lines, prepares and analyzes calibration curves for each analytical line, makes density calculations for each such line corrected for background, converts densities into percentage of element, and finally prints out a complete analytical report. This system has been thoroughly tested and is now being used for analyses. More analytical lines as well as many other elaborations will be added to the computer program as experience dictates. The inclusion of spectral interference data and matrix effects is anticipated with especially high hopes for improving the accuracy of the usual spectrochemical results.

ANALYSIS OF WATER

Atomic-absorption spectrophotometric method for aluminum

An atomic-absorption spectrophotometric method involving chelation and extraction was developed by M. J. Fishman for the determination of traces of aluminum down to 10 μg/l. The element is chelated at pH 8.0 with 8-hydroxyquinoline and extracted with methyl isobutyl ketone (MIBK), and the extract is aspirated into the nitrous-oxide flame of the spectrophotometer. None of the substances commonly occurring in water interferes, except magnesium. Magnesium forms an insoluble chelate with 8-hydroxyquinoline at pH 8.0 and tends to coprecipitate aluminum 8-hydroxyquinolate. However, the magnesium precipitate forms only slowly, and its interference is avoided if the aluminum chelate is extracted immediately.

Automated determinations using the AutoAnalyzer

Technicon AutoAnalyzer methods for the determination of mercury, fluoride ion, and manganese were investigated by D. E. Erdmann. Mercury is determined by flameless atomic-absorption spectrophotometry following a permanganate-persulfate digestion to decompose organic mercury-containing compounds and subsequent reduction of the mercury(II) ion to elemental mercury. The method quantitatively determines mercury concentrations down to 0.5 μg/l. Fluoride ion and manganese are determined colorimetrically using xylenol orange and formaldoxime methods, respectively. Concentrations of as little as 0.1 mg/l of fluoride ion and 10 μg/l of manganese can be readily determined. Sampling rates for these determinations range from 20 per hr for mercury and fluoride to 30 per hr for manganese.

Trace elements by neutron-activation analysis

A neutron-activation method for the simultaneous determination of Sb, As, Cd, Co, Cu, Cr, Eu, Fe, La, Mn, Hg, Mo, Sm, Sc, and Zn was developed by L. L. Thatcher. The sensitivity for mercury, 0.2 μg/l, is inferior to that obtainable by a neutron-activation method specific for mercury.

Organic constituents

R. L. Malcolm, J. A. Leenheer, L. A. Eccles, and P. W. McKinley investigated a number of factors for their effects on the measurement of dissolved organic carbon. Pressure filtration of the sample through a 0.45-μm silver filter partitioned the organic carbon between dissolved and suspended phases with minimal adsorption on, or contamination by, the filter medium. Mercuric chloride or sodium azide, added to the samples as a preservative, interfered with the determination of organic carbon, and freezing the samples resulted in precipitates difficult to dissolve. The best method of preserving samples appeared to be ice chilling of a filtered sample collected in a serum bottle sealed by a septum.

Freeze concentration was found to be preferable to freeze drying as a means of concentrating trace-organic constituents, according to investigations conducted by J. A. Leenheer and R. L. Malcolm. The organic molecules in freeze-concentrated solutions retained the electrical-charge characteristics they possessed in the original sample, whereas freeze-dried samples were partially denatured.

M. C. Goldberg and L. L. DeLong developed an extraction technique that permits the use of any imiscible solvent to extract and concentrate dissolved organic substances from any desired volume of water. Dipole moment data are used to indicate the optimum solute-solvent combination. Use of this technique coupled with Kuderna-Danish concentration and microvigreaux column distillation permits a sevenfold concentration of trace organic constituents and makes possible their determination at concentration levels as low as 10 pg/l(picograms per liter).

Pesticides

A column-chromatographic analytical scheme for the separation of PCB and chloronaphthalenes from pesticides commonly found in water and sediment was developed by D. F. Goerlitz and L. M. Law. The method was successfully applied to an investigation of the extent of PCB contamination in bottom material of the Sacramento River in California.

Chlorinated naphthalenes have been suggested as an additional source of interference in the gas-chromatographic determination of organochlorine pesticides. Chlorinated naphthalenes are manufactured for uses analogous to those of PCB compounds, which are important environmental contaminants. Goerlitz and Law showed, by means of gas chromatography and mass spectrometry, which of the chloronaphthalene isomers may possibly interfere with gas-chromatographic analysis for pesticides.

GEOLOGY AND HYDROLOGY APPLIED TO ENGINEERING AND THE PUBLIC WELFARE

EARTHQUAKE STUDIES

GEOPHYSICAL STUDIES

Microearthquake studies

The study of microearthquakes provides insight into the physical and tectonic processes which operate in a seismic region. W. H. K. Lee (1971) is completing an analysis of earthquakes in the greater San Francisco Bay region, here defined to include an area in central California extending from Santa Rosa in the north to Parkfield in the south, for the years 1969 to 1971. The USGS has, since 1967, built up a dense telemetered network of seismograph stations to study local earthquakes in detail. At present this network of over 80 closely spaced stations permits precise location of thousands of local earthquakes each year. Results for a 32-month period ending August 31, 1971 (with over 5,000 earthquakes located) show that most earthquakes occurred in narrow, nearly vertical zones at shallow depths (<15 km) along the San Andreas fault system. The most active region is near Hollister where much of the earthquake activity seems to be transferred from the main San Andreas fault to its subsidiary branches, the Sargent, Calaveras, and Hayward faults. Seismicity along the San Andreas fault on the San Francisco Peninsula is comparably low. Fault-plane solutions for several hundred earthquakes indicate mostly right-lateral strike-slip motion.

W. H. K. Lee, R. E. Bennett, and K. L. Meagher (1972) have devised a method to determine the magnitude of local earthquakes from signal duration. Richter magnitude of local earthquakes may be conveniently estimated from signal duration using an empirical formula:

$$\hat{M} = -0.87 + 2.00 \log \tau + 0.0035\Delta$$

where $\hat{M}$ is an estimate of Richter magnitude; τ, signal duration in seconds; and Δ, epicentral distance in kilometers. This magnitude scale was established by analyzing the relation between Richter magnitude, signal duration, and epicentral distance for 351 earthquakes in central California.

Analysis of the aftershocks of the San Fernando earthquake by R. L. Wesson and D. H. Wilson (1972) reveals the geometry of fault surfaces at depth. Hypocenters of over 700 aftershocks of the San Fernando earthquake have been determined. The majority of these lie on a V-shaped structural feature whose apex points north and dips ≈40° N. The zone of observed surface breakage approximately closes the open end of the V. This pattern of hypocenters supports the idea of a main shock resulting from elastic strain release on a north-dipping thrust fault. In this model the aftershocks result from stress concentrations on the margins of the slipped area. Fault plane solutions for over 35 events are predominantly thrust type. Strike-slip type solutions are interpreted as resulting from irregularities in the fault surface. The distribution of aftershocks also suggests movement on imbricate faults.

Seismic networks have been installed in the vicinity of Libby Reservoir, northwestern Montana; New Melones Reservoir, Calif., and Dworshak Reservoir, Idaho. These networks collect data on the background seismicity of these areas prior to, during, and after the filling of the reservoirs. In addition, seismicity has been monitored at the sites of proposed injection wells in Childress County, Tex., and near Tuscaloosa, Ala. J. C. Roller has observed no natural earthquake activity near the proposed injection wells.

E. T. Endo and R. Y. Koyanagi continued observation and analysis of earthquakes associated with volcanism on the island of Hawaii. During 1971 the Hawaiian Volcano Observatory seismometer net detected over 6,500 microearthquakes of sufficient magnitude for computer locations. An increased level of microearthquake activity during the last half of 1971 was associated with two volcanic eruptions at Kilauea in August and September. The late September eruption on the southwest rift was preceded by shallow events near the summit of Kilauea, and there were numerous microearthquakes along the rift zone during and after the eruption. A high level of seismic activity continued to the end of the year.

An 11-station seismic network was installed in the highly active seismic zone of southern Alaska in August and September 1971. Seven stations are located in the Cook Inlet area with a separation on the order of 50 km between stations; the others are located in the Chugach Mountains, three along the Richardson Highway, and one at Cordova. Data from the new stations should significantly improve the precision and accuracy of earthquake locations in coastal southern Alaska. As many as five to 10 events per day are well recorded by the Cook Inlet stations. Analysis of this data by R. A. Page and

J. C. Lahr (1972) suggests that most of these shocks occur in the previously recognized Benioff zone.

R. M. Hamilton and L. J. P. Muffler (1972) recorded microearthquakes in The Geysers area of northern California for 3 weeks with a radio-telemetry array of eight seismograph stations to examine their distribution with respect to the area developed for geothermal power. Locations were determined for 53 earthquakes within about 10 km of The Geysers. Most epicenters lie in a zone about 4 km long and 1 km wide passing through the geothermal field along a principal fault zone. Focal depths in this trend range from near surface to about 4 km. A composite fault-plane solution indicates dextral strike-slip faulting on a north-northwest-striking plane subparallel with the regional fault pattern. The results of this study suggest that accurate mapping of microearthquakes can be useful in the exploration for geothermal resources if the earthquakes studied here are not somehow caused by development of the field.

Many studies of microearthquakes rely upon continuously operating magnetic-tape instrumentation systems to record the output from multistation local seismic arrays. The data usually are timed and otherwise reduced by hand methods. S. W. Stewart and P. R. Stevenson are now testing a computer-based system for the automatic handling and processing of magnetic tapes generated by local seismic arrays. Three portable, radiotelemetry arrays have been designed and constructed by W. H. Jackson and Herbert Mills for this specific purpose. The analysis is conveniently divided into two steps. In the first step a small computer is used to search the magnetic tape for microearthquakes and to transfer the events to a digital magnetic tape for further processing. In this step, time-compression ratios as great as 80:1 are used; for example, a tape recorded over a 5-day interval can be searched in 1½ hr. In the second step a larger, general-purpose computer is used to automatically time, locate, and plot the microearthquakes detected in the first step. Early results indicate that the system works satisfactorily for microearthquakes with clear onsets, recorded in relatively dense local seismic arrays. Computer-based detection and location techniques, such as those described here, have further application in real-time processing modes as well. In this mode seismic telemetry lines can be connected directly to the computer, and microearthquake locations determined within approximately 1 min after the occurrence of the event. This mode of operation, currently under investigation, has application to remote sensing of earthquakes in volcanic or other potentially hazardous regions.

Earthquake mechanics

Research on seismic source characteristics in the southern California region by W. R. Thatcher (USGS) and T. C. Hanks (California Inst. Technology) has demonstrated the practical utility of locally recorded shear-wave seismograms in obtaining source dimensions and stress drops of moderate-size earthquakes of magnitude 2 to 6 (Thatcher, 1972; Thatcher and Hanks, 1972). Source sizes between 1 and 20 km and average stress drops ranging from about 1 to 100 bars have been measured, and regional localization of these parameters within the southern California area is presently being investigated. Previous studies of these source characteristics have largely been confined to relatively few large earthquakes with measurable surface faulting.

A. H. Lachenbruch and J. H. Sass analyzed the meager data presently available on heat flow and radioactivity near the San Andreas fault. Taken together, the generally high heat flow, the apparently normal levels of crustal radioactivity in Franciscan and Salinian rocks, and the absence of any seismic indications of widespread partial melting in the crust and upper mantle point to a significant and sizable, though puzzling, thermal anomaly in the crust over a broad sinuous band roughly coincident with the traces of the San Andreas and related faults. The magnitude and direction of horizontal temperature gradients in the crust may be related to different modes of strain release on different segments of the fault system.

The concepts of plate tectonics provide a framework for studies of earthquake generation. A. H. Lachenbruch (USGS) and G. A. Thompson (Stanford Univ.) (1972) suggest that the persistent near-orthogonal pattern formed by oceanic ridges and transform faults defies explanation in terms of rigid plates because it depends on the energy of plate deformation. For passive spreading, it is likely that the ridges and transforms adjust to a configuration offering minimum resistance to plate separation. Under reasonable assumptions, this implies that it is much more difficult for diverging plates to spread a kilometer of ridge than to slip a kilometer of transform fault. If the patterns observed at the surface extend to lithospheric depths, the resisting force at spreading centers could play a significant role in the dynamics of plate-tectonic systems.

Crustal stress and strain studies

Knowledge of the state of stress and strain in the earth's crust is a fundamental requirement for mechanistic earthquake prediction. R. V. de la Cruz has developed an instrument composed of extremely sensitive temperature-compensated semiconductor strain gauges. The gauges are bonded inside an epoxy-filled cylinder and securely embedded in a borehole. This instrument makes possible the measurement of stress changes associated with earthquakes and other tectonic events.

M. D. Wood and R. V. Allen have developed an inexpensive borehole tiltmeter that is capable of resolving tilts to 10^{-8} radians with secular drift as low as 10^{-6} radian per yr in a vault. Comparable results have been obtained in a shallow borehole during rain-free periods. Proper site selection and emplacement procedures for the boreholes are critical to operation at such sensitivities and drift rates. Results from the San Fernando aftershock tilt and tidal gravity experiment at Sylmar, Calif., and data from the San Francisco Bay region indicate that, if anomalous tilts precede small magnitude

events (magnitude<5), they are less than the range of the mean daily solid earth tide. Derivation of a transfer function for the effect of rainfall on recorded tilt permits a prediction of tilt to $\pm 4\times10^{-7}$ radians over a period of a few hours. Prediction of the response of the earth to meteorological activity is essential in separating this response from that which may be earthquake related.

J. C. Savage, R. O. Burford, and W. T. Kinoshita have reexamined geodetic data along the San Andreas fault between lat 36° N. and 38° N. (that is, from Parkfield to San Francisco) to estimate the current relative movement between the American and Pacific plates across the San Andreas fault system. The average right-lateral motion is estimated to be 32±5 mm/yr for the period 1907 to 1971. Between lat 36° N. and 37° N. (Parkfield to Hollister) most, if not all, of the plate motion is accommodated by fault creep. Between 37° N. and 38° N. (Hollister to San Francisco) the mode of accommodation is apparently partly fault creep and partly strain accumulation concentrated near the faults. This new estimate of relative plate motion is substantially less than previous estimates of 50 to 60 mm/yr (J. C. Savage, 1971).

A joint study of the gravity changes associated with the San Fernando earthquake of February 9, 1971, has been made by H. W. Oliver and S. L. Robbins (USGS), R. W. Alewine (California Inst. Technology), and Shawn Biehler (Univ. California, Riverside). Reoccupation of 49 gravity stations in March 1971, originally established between 1958 and 1970, indicates that gravity decreased as much as 0.45 mgal. The gravity decrease reaches this maximum just north of the Tujunga segment of tectonic ruptures and drops off farther to the north similar to the changes in elevation determined by releveling. The relation between the two sets of data is nearly linear and can be approximated by the least-squares line

$$\Delta g = -0.215\Delta E \pm 0.26$$

where Δg=change in gravity in milligals and
ΔE=change in elevation in meters plus or minus standard deviation.

Field and laboratory studies of earthquake control

C. B. Raleigh, J. H. Healy, J. P. Bohn, and J. D. Bredehoeft continued the earthquake control experiment in Rangely, Colo., oil field. Beginning in November 1970, fluid pressures in the seismically active part of the oil field were reduced by backflowing four wells. Earthquakes which had been occurring with a frequency of about 100 per month died off to only a few per month within 1 km of the wells. In May 1971, water was reintroduced into the wells and the fluid pressure as of December 1971 had risen to within 21 bars of the November 1970 bottom-hole pressure of 278 bars. Earthquakes near the bottom of the holes are still infrequent. Measurements of the state of stress near the earthquake focal region indicate that the failure strength of the rock should be exceeded when the bottom-hole pressure is about 257 bars. M. K. Hubbert and W. W. Rubey's theory of effective stress adequately explains the triggering of earthquakes by fluid pressure in the Rangely oil field.

J. D. Byerlee, M. G. Wilson, and Louis Peselnick (1972) carried out laboratory experiments to study elastic shock activity during the injection of water into stressed rock containing a preexisting fault. The rock studied was Weber Sandstone from the Rangely oil field. In the experiments the confining pressure was 1,200 bars, and the differential stress on the sample was 3,600 bars. The piston applying the axial stress was held fixed after the initial application of load. The elastic shock activity was detected with piezoelectric transducers, and the number of shocks per unit time was recorded with a pulse-height analyzer. In the experiments the injection pressure was kept constant for a period of 15 min at 600 bars and then dropped to zero for 15 min. The number of shocks per minute were recorded for three such cycles. It was found that the elastic shock activity increased during pore pressure increase and decreased when the pore pressure was decreased. A significant result was that the maximum number of shocks per unit time decreased with each succeeding injection cycle. This decrease was because the elastic shock activity is a function of the applied differential stress, and in the experiments the load on the sample dropped slightly as the sample deformed. In a smaller way the earthquake activity on a fault in an active tectonic region may decrease during fluid injection at constant pressure if the shear stress decreases as the fault moves. Earthquakes triggered by fluid injection in a tectonically inactive region (fixed displacement boundary condition) should migrate with time, decreasing near the point of injection as stress is relieved by the earthquakes.

GEOLOGIC STUDIES

SAN FERNANDO, CALIFORNIA, EARTHQUAKE OF FEBRUARY 9, 1971

Since publication of a preliminary report on the San Fernando earthquake (U.S. Geological Survey and others, 1971), Richter magnitude 6.4, continuing studies on surface effects of the earthquake and on geologic relations of the San Fernando fault zone have yielded important additions and refinements to the earlier data. A study by R. F. Yerkes on shaking intensity and damage and their relation to geology points out that unusually severe shaking, locally exceeding 100 percent g, (980.665 cm sec^{-2}), characterized a belt along the southwestern front of the San Gabriel Mountains about midway between the main-shock epicenter and the surface rupture 8 km to the south. Strong shaking with measured horizontal accelerations of 10 to 20 percent g extended southward and southeastward to the downtown Los Angeles and Pasadena areas, 40 km from the epicenter. More than 25 percent of all dwellings in the area of most intense shaking north of the rupture zone had losses exceeding 5 percent of

pre-earthquake market value. Damage was concentrated along the rupture zone and along boundaries between relatively unconsolidated alluvial deposits and harder, denser rocks; such boundaries in this area commonly coincide with east- and southeast-trending north-dipping reverse faults of the Santa Susana and Sierra Madre systems that bound the San Gabriel Mountains on the south.

Dating of past movement on the San Fernando fault zone by M. G. Bonilla suggests that substantial surface faulting and a strong earthquake occurred about 200 yr ago at the same location as the 1971 ground rupturing. The time of the faulting and the earthquake is based on the radiocarbon age of wood found in a trench cut across the pre-1971 fault scarp. The vertical component of fault displacement on the old scarp was greater than that of the 1971 movement at the same place. Because a rather good correlation exists between surface displacement on a fault and the magnitude of the associated earthquake (M. G. Bonilla and J. M. Buchanan, 1970), the earthquake that occurred about 200 yr ago was probably larger than the 1971 shock.

One of the most complex and puzzling areas of surface rupturing associated with the 1971 earthquake lies in and near the San Fernando Industrial Park on the east bank of Pacoima Wash. Surface ruptures previously mapped there were complex in terms of the locations and geometry of individual fault breaks as well as in the apparent discontinuity of ruptures between the main Sylmar and Tujunga segments of the San Fernando fault zone. Much of the surface deformation there, according to R. V. Sharp, now appears to have taken the form of bending (in the horizontal plane) rather than discrete rupturing. Mapping of warped pavements, drainage ditches, fences, and buildings shows that the known surface rupturing occurred within relatively broad zones of surface bending. These zones of bending are themselves very complex in their geometry, but they indicate that the apparent gap in the surface deformation near the industrial park is substantially less than reported earlier. Instead of dying out westward at about the same latitude as the beginning of the Sylmar segment, the Tujunga segment overlaps the Sylmar segment about 0.4 mi in an en echelon arrangement. One continuous zone of bending at the western end of the Tujunga segment near Pacoima Wash approaches the Sylmar segment to within 0.2 mi.

Another zone of surface bending was recognized by R. V. Sharp in the internal 0.25 to 0.8 mi east of Little Tujunga Wash. In this area the bending was chiefly in the vertical direction rather than horizontal. The zone was mapped by measuring tilts of houses and swimming pools that were originally constructed with essentially horizontal floors and perimeter gutters. Tilts of as much as 2½ degrees from the horizontal were detected on the floor lines of many houses. This zone of vertical bending reveals that surficial deformation was much more continuous than indicated by the few previously mapped surface fractures in the same area.

Additional data on the direction and amount of tectonic slip on the surface ruptures were also obtained by R. V. Sharp in subsequent study of the San Fernando earthquake. By geometrically combining apparent offsets in the horizontal plane with vertical separation across the scarps, tectonic slip vectors were determined at 24 locations along the zones of surface rupturing. Generally along the Tujunga segment the slip vectors reveal a marked thrust component of movement in addition to a left-lateral component. In contrast, slip vectors determined for the Sylmar and Mission Wells segments of rupturing generally indicate much smaller to negligible thrust components and instead reflect movement consisting of predominantly left-lateral and vertical components. The positions and orientations of the rupture traces, when combined with dips inferred from the slip vectors, suggest substantial curvature of the principal fault surface at depth. Scattered exposures of strongly deformed sediments that underlie the San Fernando area suggest that the Sylmar and Mission Wells segments are essentially bedding plane faults similar to the relation of faulting to bedding observed at the surface along the Tujunga segment.

SAN FRANCISCO BAY REGION

A comparison of mapped active faults, small earthquake activity, and measurable tectonic creep in the San Francisco Bay region by R. D. Brown, Jr., and W. H. K. Lee (1971) shows that small earthquakes are localized chiefly along or near mapped active fault strands and that the most seismically active breaks are those that also exhibit continuing tectonic creep. This comparison also shows that many known active fault segments are now virtually devoid of both small earthquake activity and tectonic creep; such quiet fault segments are nevertheless potentially capable of producing great earthquakes as they have in the past. Although a lack of agreement in locations of geologically mapped faults and seismologically defined fault zones still exists, empirical corrections to the crustal model have substantially improved the resolving power of the seismological technique of delineating active faults by epicenter locations.

GABILAN RANGE

D. C. Ross has mapped 10 granitic formations in a basement terrane that covers more than 780 km^2 of the Salinian block adjacent to the San Andreas fault. Success in this first attempt to delineate basement formations in the poorly exposed crystalline terrane promises hope for the eventual determination of the distribution and composition of basement units throughout the Salinian block. A firm basement tie over such a large area on one side of the San Andreas fault improves the possibility of identification of the exposed parts of any displaced counterparts.

SANTA MONICA–BAJA CALIFORNIA ZONE OF DEFORMATION

Existence of a major linear zone of deformation that extends southeastward from near Santa Monica, Calif., into Baja California has been verified by J. I. Ziony and H. C. Wagner in their compilation of a geologic environmental map of coastal southern California for the AEC. The zone is defined at the surface by discontinuous, generally northwest-trending faults and folds within Tertiary and Quaternary strata; these structural features form a discrete belt from 1 to 13 km wide which extends for at least 240 km. The Newport-Inglewood zone, the northernmost segment, can be projected offshore into a similar band of en echelon folds and faults that lie near the edge of the coastal shelf between Laguna Beach and La Jolla. The latter features appear to connect with a zone of discontinuous Quaternary faults that are exposed in the San Diego area, some of which extend into Baja California.

Although the nature of the Santa Monica–Baja California zone of deformation at depth is unknown, the persistence of a discrete belt near the surface suggests a through-going tectonic discontinuity within the underlying basement rocks. The length and trend of such a tectonic zone would compare to that of the San Jacinto and Whittier-Elsinore fault zones which lie to the east. Because the 1933 Long Beach earthquake (magnitude 6.3) may be associated with the Newport-Inglewood segment and because Quaternary deformation is evident at many places along the zone, a potential for moderate to large earthquakes probably exists along all segments of the zone.

SAN JACINTO FAULT ZONE, NORTHWESTERN IMPERIAL VALLEY

M. M. Clark, Arthur Grantz, and Meyer Rubin (1972) have estimated the recurrence interval for displacement equal to that which occurred on the Coyote Creek fault, a main strand of the San Jacinto fault zone, during the 1968 Borrego Mountain earthquake (magnitude 6.4). They compared the 1968 vertical component of displacement with that of earlier faulting events recorded in flat-lying sediments of Holocene Lake Cahuilla which covered parts of the fault until at least 800 yr ago. Three sets of measurements of vertical displacement on carbon-14-dated beds exposed in trenches across the fault suggest that the recurrence interval along the Coyote Creek fault for 1968-size seismic events is about 200 yr, assuming that all past earthquakes with surface movement were of comparable magnitude. This recurrence interval is compatible with those estimated for the San Andreas fault north of the Transverse Ranges and for the San Jacinto fault zone.

Rates of late Holocene strike-slip displacement along the Coyote Creek fault were derived in two different ways from measured rates of vertical displacement. Both methods suggest that the strike-slip rate is about 3 min/yr, a value consistent with an earlier estimated minimum rate of 2.5 min/yr for the parent San Jacinto fault since Pleistocene time. The trench exposures additionally showed that total vertical deformation (displacement plus bending) across a fault in poorly consolidated deposits may be greater by a factor of two than the fault offset alone; thus, estimates of seismic movement and stress drop may also be in error by a factor of two due to this effect. Repetitive movements on the Coyote Creek fault over the past 300 yr appear to have been confined generally to a very narrow zone along the fault; in one place at least three and possibly 17 events of fault movement have taken place along a planar zone only a few tens of millimeters wide.

GARLOCK FAULT

Rates of tectonic deformation along the Garlock fault have been established by studies of Quaternary sediments along the south side of Searles Valley by G. I. Smith. The sediments are divided into six stratigraphic units with successively younger ages and diminishing structural disturbance. The oldest unit is deformed by faults and tilted to vertical dips but cannot be used to establish amounts of horizontal or vertical displacement. The next younger unit, probably of middle or late middle Pleistocene age, is faulted and tilted as much as 25°, suggesting a few hundred meters of upwarp; stream channels incised in this unit are offset left-laterally as much as 65 m. The overlying two units are lacustrine gravels that represent beaches which formed when early and late Wisconsin lakes were at their highest levels. In most other parts of Searles Valley correlative gravels lie about 15 m and 10 m lower than the lower and upper Wisconsin deposits respectively. This position suggests a rate of upwarping between 4 and 29 cm per 1000 yr between the early Wisconsin lake (40,000–130,000 yr B.P.) and the late Wisconsin lake (10,000–23,000 yr B.P.). Upwarping has apparently increased to a rate between 44 and 100 cm per 1000 yr since late Wisconsin time. Few of the most prominent scarps on this segment of the Garlock fault, however, are older than 50,000 yr (G. I. Smith, 1960), suggesting that upwarping rather than fault displacement represents most of the vertical deformation since that time. Left-lateral displacement of stream channels, cut since the lake retreated 10,000 yr ago, is as much as 13 m, indicating horizontal offset at a rate that exceeds 1.3 m per 1,000 yr. The two youngest stratigraphic units, identified by geological mapping as being of Holocene age, may be uplifted and offset left laterally a meter or two.

ENGINEERING GEOLOGY

Environmental impact of the trans-Alaska pipeline

Members of the USGS and officials of the Alyeska Pipeline Service Co. engaged in a continual dialogue directed toward solving the many serious engineering-geologic problems that

would be posed by the construction and operation of a large-diameter pipeline designed to transport hot oil approximately 800 mi from Prudhoe Bay to Valdez. Sufficient progress was made to evaluate the proposed pipeline for the "Final Environmental Impact Statement" released by the Department of the Interior. Final technical stipulations controlling the planning, construction, and operation of the pipeline were completed and published by the Department of the Interior.

Engineering-geologic maps of the entire pipeline route were published and distributed to interested parties (O. J. Ferrians, Jr., 1971a,b,c,d; Reuben Kachadoorian, 1971a,b,c; F. R. Weber, 1971a,b). These maps were used by USGS members as an aid in evaluating the proposed pipeline route for the "Final Environmental Impact Statement."

Studies of earthquake stability of surficial deposits

Most previous investigators have approached the seismic response of layered ground by numerical methods or by either single-layer or first-mode approximations. Unfortunately, the numerical approach does not often lead to any further understanding of the dynamic behavior of the system, and the single-layer or first-mode approximation does not always give reliable results. In a recent study, A. T. F. Chen (1971) has shown that systems with two or more layers can be analyzed mostly from graphic plots with results that are comparable with those from a computer analysis. In addition, his study shows conditions under which a layer may be considered rigid or a thin layer may be ignored and under which contributions from higher modes are likely to be greater than those from the first mode.

Glaciomarine deposits, which underlie surfaces that slope gently from the base of the steep mountainsides to the edges of bluffs bounding the waterways near Juneau, Alaska, provide much of the relatively flat land available for urban expansion around Alaska's capital city. These deposits consist of a stoney till-like material. They have sometimes been compared with the Bootlegger Cove Clay of the Anchorage area and probably were formed in a similar environment of deposition. Detailed mapping by R. D. Miller (1972) and results of laboratory tests on numerous samples reveal that these glaciomarine materials are firmer, harder, and more stable than the Bootlegger Cove Clay, however. In the deposits at Juneau, cobbles and boulders are scattered among numerous pebbles and granules in a sandy, silty matrix that has a relatively low content of natural water. The relatively superior physical properties of the materials make it unlikely that massive landslides, such as occurred at Anchorage in 1964, would form in these deposits as a result of strong shaking in response to a severe earthquake.

Rupturing and shifting of the earth's surface occurred at several places on very gentle slopes in the vicinity of the Van Norman Lakes during the 1971 San Fernando, Calif., earthquake. T. L. Youd (1971) investigated the origin of the ruptures and displacements and obtained information about the phenomena that led to their occurrence. Surficial features such as ruptures and sand boils were mapped, points with known preearthquake locations were surveyed, and subsurface data gathered. Youd concluded that landsliding, predominantly of the lateral spreading type, was the cause of the ruptures and differential displacements. His study also led to the tentative conclusion that partial or complete liquefaction of subsurface soils allowed the slides to move on the very gentle slopes.

Debris flows generated by soil slips are a major hazard in southern California

R. H. Campbell has determined, from the record of the past decade, that debris flows generated by soil slips during rainstorms present a greater risk of bodily injury to southern California residents than all other classes of slope failure combined. Debris flows of this probable origin have been directly responsible for at least 23 fatalities in the greater Los Angeles area since 1962, all occasioned by the damage or collapse of occupied structures when those structures suffered inundation by mud and (or) high-velocity impact by muddy debris.

Soil slips occur when the infiltration of water into the soil mantle on a slope exceeds the rate of escape of water by percolation downslope and into the underlying subsoil material and a perched water table is thus formed approximately parallel to the slope. A perched water table cannot begin to form, however, until the moisture in the affected soil zone has been brought to field capacity by previous rainfall. The temporary piezometric head reduces the shearing resistance of the soil slab and, if the slope is steep enough, failure may result. The initial sliding remolds the soil of the saturated zone to a fluid mud, and subsequent movement is dominated by viscous flow.

On the basis of empirical associations between debris flows and rainfall records, it seems that a seasonal rainfall total of about 10 in. is required to bring the moisture content of most of the colluvial soil of the region to field capacity and that rainfall intensity of 0.25 in./hr or more is a minimum at which surface infiltration exceeds subsoil drainage for most of the colluvial soils.

Because the relevant soil parameters and moisture conditions are measurable and because alert adults have demonstrated the ability to avoid injury from some debris flows that have been observed approaching, future injuries from this cause must be classed as mostly preventable, even though property damage may be large. The empirical associations suggest that slope maps, in conjunction with radar weather maps and a rain-gage network, may provide the basis for a warning system.

Studies of underground excavations

Detailed analysis by C. R. Dunrud of coal production during the last 2 years from three mines in the northern part of the

Sunnyside mining district, Utah, revealed a correlation between the methods used in extracting coal and the level of seismic activity as recorded by a seismic monitoring network. In these mines, two different mining methods are used—the relatively new longwall method, in which the coal is extracted in one step, and the long-employed room-and-pillar method, which basically involves two steps. In the longwall method, a continuous coal face, commonly hundreds of feet long, is cut in increments of about a foot by a moving cutter wheel, whereas, in the room-and-pillar method, openings 16 to 20 ft wide are driven into the solid coal at regular intervals in two mutually perpendicular directions, and the remaining coal pillars are extracted later. The longwall method is three to five times as efficient as the room-and-pillar method. In any given geologic and topographic setting, the longwall method seems to cause significantly less seismic activity, even when producing much higher tonnages and a greater percentage of coal reserves, than the room-and-pillar method. This suggests that the stresses produced by longwall mining are lower or less concentrated than those produced by the room-and-pillar method.

Rock mechanics investigations by J. F. Abel, Jr., and F. T. Lee in a mine at Idaho Springs, Colo., provided new insights into stress changes in rock ahead of advancing tunnels. Instruments placed ahead of a crosscut driven into a crystalline rock mass detected major stress changes 7½ tunnel-diameters ahead of the tunnel face. This finding contrasts markedly with a theoretical elastic estimate of the onset of detectable stress changes at 1 tunnel-diameter ahead of the tunnel face. In addition, a minor compressive stress concentration, which preceded the major stress change, was detected about 6 tunnel-diameters ahead of the crosscut. No such minor stress precursor has been elastically predicted.

The three-dimensional in situ stresses determined from the instrumental data recorded in the mine demonstrate that geologic structure controls stress orientations in the jointed and closely foliated gneiss and gneissic granite. Two of the computed principal stresses are parallel to the pervasive foliation, and the other principal stress is normal to it. The principal stress orientations vary approximately as the foliation attitude varies. The magnitudes of the in situ principal stresses and of the opening-induced stress changes exceeded estimates of stress magnitudes using elastic theory. The average horizontal stress components and the average vertical stress component of the in situ stress field are three times and twice as large, respectively, as those predicted from simple overburden loading. The stress field appears to have both tectonic and residual stress components, as suggested by laboratory and field information. Mining may have triggered the release of strain energy, which is concentrated along faults.

Research in rock mechanics

The anisotropic response of granite samples to mechanical loading has been observed in experiments utilizing electrical resistance strain gages. R. A. Farrow applied hydrostatic pressure to samples of Mount Airy Granite and found that differences in the changes of length appear to be related to the jointing in the rock. T. C. Nichols, Jr., drilled out cores from a 22-cm cube of Barre granite and observed one relieved surface to contract and the opposite surface to expand; dimensional changes in other directions also were anomalous; the maximum residual strains, left over from natural loading in the earth, were found by Nichols to be 0.028 percent in compression and 0.033 percent in extension.

URBAN AREA STUDIES

The Urban Studies program employs the core disciplines of the USGS—geology, geophysics, hydrology, geography, and topography—to acquire a sound knowledge base for regional urban planning and development. The program was initiated in January 1970 with the San Francisco Bay region study and was expanded in fiscal year 1972 to include six other urban-centered areas: Seattle-Puget Sound, Phoenix-Tucson, Denver, Pittsburgh, Connecticut Valley, and Baltimore-Washington. The areas were selected on the basis of need for earth science data, geologic and geographic diversity, amount of basic data already in hand, the availability of knowledgeable personnel in the particular area involved, and local interest and willingness to cooperate.

SAN FRANCISCO BAY REGION ENVIRONMENT AND RESOURCES PLANNING STUDY

In October 1971, the program design for the San Francisco Bay study was released, containing detailed descriptions of the various program elements in earth science and urban planning for the nine-county bay region. An important feature of the study is its innovative publication program. The initial set of maps and reports incorporates data that are generally of a highly scientific and technical nature and useful to limited audiences. A second set of reports, the technical series, contains material derived from the basic data; these items are also oriented toward a technically trained audience, but one that is more specifically involved with development and planning. The final set of reports, tentatively called the interpretive series, is designed for use by a wide audience of planners, decision-makers, and the general public and has the greatest potential impact on land-use policies and decisions.

The study has provided the impetus for cooperative thesis projects with local college and university earth science departments. Very few students from these schools were working in the bay area before the project began in 1969, but more than 20 are now working on theses that will provide basic data for the project. Twelve students from San Jose State College, for example, are mapping the geology along active

faults such as the San Andreas, Sargent, and Calaveras. Among the results of their work has been the discovery of extensive and previously unrecognized thrusting associated with the Sargent fault. Several of the students are also employed part time by the Survey, and some of their thesis maps judged to be of sufficient quality have been released through USGS open files.

GEOLOGICAL AND GEOPHYSICAL STUDIES

Twenty-two reports in the basic data contribution series have been released, dealing with geological and geophysical aspects of the San Francisco Bay region. These include: (1) various studies related to the active faults in the area, (2) geologic maps emphasizing the engineering properties of the identified units and their regional planning significance, (3) geophysical data largely in areas covered by the bay, and (4) maps showing the relative abundance of landslides and other surficial deposits.

Active faults

A comparison of the distribution of active faults, small earthquake activity, and measurable tectonic creep in the San Francisco Bay region by R. D. Brown, Jr., and W. H. K. Lee (1971) is discussed in the section "Earthquake Studies" (p. A158). As a result of this study and of earlier published maps and reports, there have been a number of significant land-use decisions including two bills passed by the California State legislature dealing with seismic safety elements in the State planning law and a decision by one of the largest savings and loan organizations in the State to examine critically its real estate loan portfolio in areas containing active faults as mapped by the USGS.

Slope stability and engineering behavior of bedrock

Geologic studies by M. C. Blake, Jr., W. R. Cotton, K. F. Fox, Jr., Julius Schlocker, J. D. Sims, and others have revealed the widespread presence of melange, an intensely sheared unit within the Franciscan Formation which forms the basement over much of the San Francisco Bay area. The melange consists of a soft, clayey, highly sheared matrix surrounding hard rock masses. The hard pieces are of all sizes up to hundreds of feet and include sandstone, chert, volcanic rocks, metamorphic rocks, and serpentine. The smaller pieces, up to 20 ft in diameter, appear rounded or spheroidal in shape and have slickensides. Laboratory studies by Schlocker indicate that the matrix is generally shale altered to swelling clay containing large amounts of montmorillonite and chlorite. The matrix is weak and plastic when wet and strongly influences the physical properties of the entire mass. Consequently, landslides are common slopes of melange, and the erratic distribution of hard coherent rock masses within the melange gives rise to considerable local variation in physical characteristics and may lead to erroneous appraisal of foundation conditions unless the nature of the melange is understood.

Landslides and other surficial deposits

During fiscal year 1972, a number of maps were published dealing with landslides and other surficial deposits in the San Francisco Bay area (T. H. Nilsen, 1971, 1972). These maps and accompanying texts will eventually be available for the entire study area. They are reconnaissance in nature, being prepared entirely by examination of aerial photographs, and represent the first stage in a detailed study of surficial deposits in the bay region. These preliminary photointerpretation maps, however, provide land-use planners with immediately useful information about the regional distribution of landslide and other surficial deposits.

Physical properties of unconsolidated deposits

Maps showing the distribution of late Cenozoic deposits in Santa Clara County have been released (E. J. Helley and E. E. Brabb, 1971). These provide basic information on the character and distribution of several types of geologically young formations. Though not specifically designed for site evaluation, the maps can be used to indicate the general types of problems which may be encountered by planners and developers. For example, areas underlain by deposits with low density, high moisture content, and low penetrometer values, such as interfluvial basin deposits, may not support foundations well and are also likely to be poor places for septic tanks. Similar mapping is being done throughout the remainder of the San Francisco Bay area by E. J. Helley, K. R. Lajoie, and others.

HYDROLOGIC STUDIES

Twelve basic-data reports and three technical reports dealing with hydrologic elements in the San Francisco Bay region were released in fiscal year 1972. In a continuing study of the ground-water resources, D. A. Webster has completed work on two maps which will provide regional planners with useful information about the availability and chemical quality of ground water within the region. One map shows four ranges in expected aquifer yields and is keyed to potential land use if other water sources were not available. The second map shows areas where nitrate, boron, and dissolved solids concentrations have been found in ground water in amounts sufficiently high to be of concern to an appreciable segment of users; it contains a series of graphs depicting the trends in dissolved solids concentrations of samples from numerous monitor wells during the period 1960 to 1970.

Water-quality (limnological) surveys on 21 lakes and reservoirs in the San Francisco Bay area have been made by R. C. Averett and L. J. Britton. The results show strong summer thermal stratification. The summer oxygen profiles displayed

wide variation among the lakes; most, however, had a severe metalimnetic oxygen depletion.

A map in preparation by J. R. Ritter and W. R. Dupre shows areas in the San Francisco Bay region that would be inundated by a tsunami-produced runup of 20 ft. Areas most likely to be inundated by such a runup are marshlands, tidal flats, and areas that have been artificially filled. Some of these filled areas have been used for housing and industrial development.

Density-induced advective flow, generated largely by Sacramento and San Joaquin River discharge, occurs throughout the year for a wide range of river discharge in the north and central bays. This estuarine circulation pattern varies seasonally in south bay, both in direction and in type of stratification. Following the highest river discharge of the year in January, there is a period of density-induced two-layer flow during late winter and early spring. During late summer, when density differences caused by river discharge are minimal and when north winds are consistently strongest, a two-layer wind-induced flow develops and is maintained until river discharge increases in late December to become the dominant factor controlling this nontidal drift in south bay (T. J. Conomos and others, 1971).

In a reconnaissance survey of sediment of the San Francisco Bay Estuary (D. H. Peterson and others, 1972), the elements Fe, Mg, Ca, Ti, Mn, B, Ba, Co, Cr, Cu, Ni, Pb, Sc, V, and Zn were detectable by semiquantitative emission-spectrographic analysis. Of these 15 elements, lead and copper apparently indicate the largest relative enrichment in surface sediment as compared with sediment unaffected by the activities of man. The modal concentrations for lead and copper are 30 ppm of dry sample weight, which is lower than might be expected for sediment in a region of high waste input. Furthermore, it seems the "reservoir" of sediment-associated lead in San Francisco Bay can account for only a fraction of man's local release of lead to the environment.

CONNECTICUT VALLEY URBAN PROJECT

In the first year of the Connecticut Valley urban pilot project, efforts were concentrated on data collection in the Hartford, Conn., area and on formulating improved methods of preparing and communicating meaningful resource data to a wide range of citizens and groups engaged in land-use planning and resource management. Published maps and reports, combined with topographic quadrangle maps, publicly available land-use maps, and unpublished data such as well logs, test-hole logs, structure-boring logs, stream-gage records, and water-quality analyses compose the input data for the project.

Discussions with planners at local and regional levels and with earth scientists interested in environmental problems suggest that simplified, single-subject maps suitable for use as overlays in various combinations will significantly enhance the usefulness of existing earth-resource data. Such flexibility of the data base is considered desirable not only because resource-management problems are extremely variable but also because critical factors such as State and local regulations, technological capability, social attitudes, and economic resources change with time. To test the concept, a series of single-subject resource maps were prepared for the Hartford North quadrangle, Connecticut. The maps are to be circulated widely to groups and individuals interested in the objectives of the project, and the subsequent feedback should help in refining and directing future activities. Slope maps and landform maps at 1:24,000 with explanatory tables to accompany each map are planned. The following slope units were selected by R. M. Barker to best characterize the topography of the Connecticut Valley area: 0 to 3 percent, 3 to 8 percent, 8 to 15 percent, 15 to 25 percent, 25 to 45 percent, and steeper than 45 percent. Tables showing degrees of slope, percentage slopes, slope ratios, and inclinations in feet per mile will accompany each map. Various natural slopes and critical slopes for construction are presented, and peculiarities of slopes and slope maps are described. To test these techniques of slope mapping and data presentation, R. M. Barker compiled a slope map of the Ellington quadrangle, Connecticut, which was put on open file in January 1972.

An experimental landforms map of the Hartford North quadrangle was compiled by R. M. Barker. Map units delineated on the landforms map are based on existing terrain characteristics. The table accompanying the map contains descriptions of: salient terrain characteristics affecting construction and land use; seasonal aspects; characteristics of water bodies; location and elevation; size, shape, local relief and slope; and geology.

In cooperation with the Ellington Task Group for the State of Connecticut, M. H. Pease, Jr., investigated the possibility of translating the bedrock geologic map of the Ellington quadrangle into terms more useful to engineers and land planners. He concluded that, within the limitations imposed by map scale, the existing geologic map is the best available representation of bedrock distribution. Most significant variations in the physical properties of the bedrock, however, are too small to show at map scale and may be as great within geologic map units as between them. Consequently the most suitable format is to key the geologic map units to a bedrock properties matrix by means of a remodeled explanation. Geologic contacts are thus retained on a new lithologic map, but stratigraphic relations of geologic units are not shown.

In the matrix, the bedrock of the quadrangle is classified according to specific differences in physical properties regardless of scale. These specific rock types are listed vertically, and their properties and uses are described in columns to the left. The explanation details for each geologic map unit and the proportion and distribution of the various rock types are listed in the matrix. The lithologic map, explanation, and bedrock properties matrix for the Ellington quadrangle are intended for publication as part of the Connecticut Valley urban project.

Seismic measurements by C. R. Tuttle, utilizing the three-component seismic method to determine bedrock "strength" (specifically bedrock elastic properties) in the field were made

on outcrops of arkose, schist, and pegmatites at three locations in the Connecticut Valley. Such field measurements provide a more realistic appraisal of true bedrock strength than laboratory tests and result in safer and (or) less expensive foundations. Elastic properties were found to vary with the type of energy source used, with the geometry of the energy source, and with the amount of bedrock fracturing. The variations appear also to be related to complex associations of rock porosity, density, and mineral grain boundaries.

GREATER PITTSBURGH REGIONAL STUDIES

The "Preliminary Geologic Map of the Midway Quadrangle, Washington County, Southwestern Pennsylvania" by J. B. Roen (1971) is the first map released by the Greater Pittsburgh regional studies under the USGS rapid-publication procedure. This procedure results in Midway quadrangle data being made available to potential users in black and white form a year or more in advance of publication by customary multicolor procedures. Features of the map of particular value to land-use planning include location of areas mined out by surface (strip) and underground methods and of landslide deposits, indicators of unstable slopes. Coal and other mineral resource data are shown as well as structure contours, tools in the search for ground water and oil and gas.

Under a grant from the USGS Greater Pittsburgh regional studies, matched by State funds, W. R. Wagner, D. R. Kelley, and W. S. Lytle of the Pennsylvania Bureau of Topographic and Geologic Survey have prepared six stratigraphic sections, text, and figures revising stratigraphic correlations in a part of the Greater Pittsburgh region. This report, on open file at Pennsylvania Survey offices, deals with the Allegheny, Conemaugh, and Monongahela Groups of the Pennsylvanian System, as well as with underlying and overlying strata. Descriptions of these rocks and their stratigraphic relations are necessary in upgrading the regional geological framework preparatory to environmental analysis.

FRONT RANGE URBAN CORRIDOR, COLORADO

Environmental geologic and hydrologic studies are underway in the Front Range urban corridor, Colorado, under the direction of W. R. Hansen. During fiscal year 1972 a preliminary engineering geologic map of the Golden quadrangle (M. E. Gardner and others, 1971) and a surficial geologic map of the Denver area (G. H. Chase and J. A. McConaghy, 1971) were released. The content, vocabulary, and format of these and other planned reports are oriented toward land-use planning and engineering construction. The maps and tables thus are useful to planners, engineers, architects, developers, builders, financiers, local-government officials and agencies, and property owners. A significant result was the release of a USGS report that identified hazardous landslide conditions in the Green Mountain suburb of Denver, which led to a temporary ban on housing development by planning officials.

PHOENIX-TUCSON URBAN AREA

In the Tucson, Ariz., metropolitan area (1,300 sq mi), six kinds of geologic-terrain maps were prepared by R. B. Morrison at 1:120,000 scale, primarily from interpretation of ultrahigh-altitude aerial photographs supplied by NASA. Three are basic-data maps: surficial geology, geomorphic features, and soil associations; three are potential land-use maps designed for regional land-use planning and showing both favorable and unfavorable geologic-terrain features: local relief and dissection, flood hazards, and construction suitability. This experiment is an extension of similar studies in this region which have produced a series of comprehensive integrated maps of a large area that display many data fundamental to proper land-use planning and development where such data have not previously been available.

INVESTIGATIONS RELATED TO NUCLEAR ENERGY

UNDERGROUND NUCLEAR EXPLOSIONS

EXPLORATION AND RESEARCH IN THE DEVELOPMENT OF SITES

Nevada Test Site

The Nevada Test Site (NTS) in southeastern Nevada is the area within which the U.S. Atomic Energy Commission (AEC) conducts most of its underground nuclear explosion tests. Since 1956 (before the first underground nuclear explosion), the USGS has made extensive and detailed studies, on behalf of the Commission, of the geology and hydrology of the NTS. These studies have provided the earth-science data necessary to insure proper environmental safeguards in the underground testing of nuclear explosives. The USGS participates in the appraisal of the safety, engineering feasibility, and postshot effects of all explosions conducted at the NTS.

Every effort is made to insure that all nuclear explosions are fully contained beneath the ground and that no radioactivity escapes to the atmosphere. To meet the containment requirement, it is necessary to determine the in situ properties of the rock in which the nuclear devices are detonated. Drill cuttings and cores are recovered for properties' measurements; geophysical logs also are interpreted for properties' measurements. R. D. Carroll and D. C. Muller have developed a method, utilizing electric and density logs, to determine the in situ water content of alluvium. At the NTS many of the nuclear tests are conducted in alluvium above the water table. Traditional methods of geophysical log interpretation cannot be used because the alluvium is only partly saturated and the

contained water is relatively fresh, generally having a resistivity in excess of 10 ohm-m. On the basis of the few drill holes that penetrate saturated alluvium below the water table, Carroll and Muller have developed an empirical relationship between the resistivity of saturated alluvium (R_o) and the porosity (Θ), according to the equation

$$R_o = 5.1\Theta^{-\frac{1}{1.76}}$$

On the assumption that the exponent in this equation is identical to that in the desaturation equation, the volume content of water in the desaturated alluvium is given by the relationship $2.52\ R_t^{-0.568}$, where R_t is the measured resistivity of the alluvium. The water content by weight is derived by dividing this expression by the density-log reading. This relationship has been checked against more than 200 measurements of water contents in cores in the range of 5 to 17 percent water by weight; the comparison gave a correlation coefficient of 0.77 with a standard deviation of 1.6 percent.

The magnitude and direction of natural in situ stress acting on an underground explosion is thought to be an important parameter affecting the behavior of rock around the explosion. J. R. Ege and H. W. Dodge, Jr., have shown that the regional stress pattern within Rainier Mesa is locally distorted by the proximity of a large downwarp in the northern part of the mesa. They further have worked cooperatively with the USBM to measure the magnitude of natural in situ stress within Rainier Mesa and have determined that the horizontal stress includes a tectonic component that exceeds the stress to be predicted from overburden pressure alone.

G. D. Bath has interpreted a closely spaced, low-level aeromagnetic survey to outline the trend and position of faults in volcanic rocks buried beneath alluvium in Yucca Flat. The prominent Yucca fault has been traced by a linear trend of negative and positive anomalies for a distance of more than 10 mi. Analysis of the anomalies and magnetic properties of drill cores indicate the anomalies are caused by the vertical displacement, along the fault, of reversely polarized Rainier Mesa ash-flow tuff that is buried beneath several hundred feet of alluvium.

Amchitka Island, Alaska

R. H. Morris and R. C. Bucknam completed a reconnaissance study of marine terraces on the islands forming the crest of the Aleutian Ridge. This study was designed to demonstrate a relationship, or lack of a relationship, between vertical movements of the islands and tsunamigenic earthquakes.

The Rat Islands, which include Amchitka Island, have active sea cliffs, well-developed intertidal platforms, and a prominent submarine platform about 300 ft below sea level. These features have not been disturbed tectonically (faulted or tilted) for the past 17,000 yr. Examination of similar geomorphic features on many of the eastern Aleutian Islands indicates that relatively stable tectonic conditions have persisted along the crest of the Aleutian Ridge as far east as the Alaska Peninsula for the past 4,000 yr, with the exception of two areas—(1) the Delarof, Tanaga, and Kanaga Islands area and (2) the Umnak and Samalga Islands area. In these two areas, Holocene emergence of 6 to 10 ft is recognized.

Morris and Bucknam conclude that large vertical displacements generally thought to produce tsunamis do not extend to the above-sea-level part of the Aleutian Ridge. A dislocation model for an underthrusting Pacific plate suggests that the large vertical displacements associated with tsunamigenic earthquakes are restricted to the Aleutian Terrace and the northern slope of the Aleutian Trench.

RESEARCH ON THE EFFECTS OF NUCLEAR EXPLOSIONS

Geologic and hydrologic effects of the Cannikin event, Amchitka Island, Alaska

The Cannikin nuclear explosion, the largest underground explosion ever detonated by the United States, was successfully executed on November 6, 1971. The USGS conducted many geologic and hydrologic investigations on Amchitka Island in support of the AEC.

The Cannikin site was thoroughly inspected by geologists R. P. Snyder, L. M. Gard, Jr., and R. H. Morris and hydrologists W. C. Ballance and D. D. Gonzalez within a few days after the explosion. Several faults within 1 mi of ground zero (GZ) were offset as much as 2 ft and permanent ground distortion was measured as far as 3 mi from GZ. The Bering Sea coast, about 1½ to 2 mi from GZ, was permanently uplifted 2 to 4 ft for a distance along the coast of about a mile. Numerous rockfalls occurred on the sea cliffs along the uplifted coastline. The total volume of all rockfalls is conservatively estimated to be about 25,000 cu yd.

The collapse sink is asymmetrical with respect to GZ. The deepest part of the sink is 1,400 ft southeast of GZ, and it subsided about 50 ft, whereas GZ subsided only about 16 ft. The asymmetry of the sink is thought to be related to preexisting faults and the dip of the rock units.

The collapse sink intercepted the stream course of White Alice Creek and reduced its flow at its discharge point into the Bering Sea from a base flow of 1,400 gpm to 60 gpm, which has been the flow for at least 7 months thereafter. It is postulated that the Cannikin explosion and subsequent collapse of the overlying rocks created a ground-water cone of depression into which ground water and the water of White Alice Creek is now flowing. It is further postulated that within 1½ to 2 yr the cone of depression will be filled, White Alice Creek will return to normal flow, and the collapse sink will be filled with water to form a lake about 20 ft deep. It will be one of the largest lakes on Amchitka Island.

Geologic effects

A synthesis of information on previous contained and

noncontained nuclear explosions at the NTS by F. A. McKeown, R. C. Bucknam, D. D. Dickey, and R. P. Snyder shows that for most of the few explosions that actively vented to the atmosphere, the surface locations of the pathways of venting were clearly controlled by natural fractures that existed prior to the explosions. In all places the fractures were in directions, or had geometric relations with the explosion cavity, for which it is reasonable to postulate that the fractures were perpendicular to the direction of least principal horizontal stress prior to the explosion. Similarly, data on tectonic strain release associated with nuclear explosions indicate the preexplosion natural stress field may be involved in controlling the path of venting.

Based on strains calculated from surface geodetic measurements made prior to and after the Jorum explosion, D. D. Dickey (1971) has inferred that the strain pattern within about 12 mi of the explosion was strongly controlled by the geologic structure of the area. He suggests that the highly fractured boundaries of volcanic caldera collapse zones in the area have influenced the manner in which stress was transferred from one zone to another, resulting in a highly complex strain pattern.

R. C. Bucknam (1972) has analyzed surface level-line data made before and after several large underground nuclear explosions. The data show that vertical displacements associated with movement on an explosion-activated fault vary in a regular manner for a considerable distance away from the fault. By application of dislocation theory to the observed vertical displacements along an explosion-activated fault, Bucknam interprets a depth of faulting of about 5,000 ft. Most fractures observed at the surface above a nuclear explosion are inferred to be relatively shallow features only indirectly related to the subsurface processes that produce the aftershock sequences that occur following large explosions.

Hydrologic effects

Cyclic and sustained ground-water fluid pressures, as measured by pressure transducers submerged in wells during two large underground nuclear explosions, were evaluated and interpreted in 1971. The two explosions monitored were the Handley event at the NTS and the Cannikin event on Amchitka Island, Alaska.

W. W. Dudley, Jr., analyzed the generated cyclic fluid pressures from the Handley event, slightly more than a megaton, and he concluded that the pressures closely followed the previously derived prediction equation, $+H=0.259\ W^{0.89}\ R^{-1.61}$, where $+H$ is the peak positive fluid pressure in bars, W is the explosive yield in kilotons, and R is the distance from the explosion in kilometers. For several hours after the explosion, pressure events recorded 3 mi away from the explosion were concluded to be related to fault movement near the monitoring well. Sustained fluid overpressures as much as 1 bar occurred from days to weeks after the explosion at a well about 3½ mi away.

D. D. Gonzalez monitored the fluid pressures in wells during the Cannikin event, less than 5 megatons, on Amchitka Island. For this location the derived response equation is $+H=21\ W^{0.33}\ R^{-1.54}$.

RELATION OF RADIOACTIVE WASTES TO THE HYDROLOGIC ENVIRONMENT

Research on the transport and ultimate fate of radioactive nuclides that might be introduced into the hydrologic environment is conducted in cooperation with the U.S. Atomic Energy Commission. Radioactive nuclides may enter the hydrologic environment either as a result of waste disposal or of accidental release; some studies develop from specific problems, but many are precautionary and designed to prepare for possible future action or to develop necessary background knowledge of the hydrologic environment in relation to (1) new waste-disposal methods and techniques or (2) utilization of these methods and techniques in various types of geohydrologic terranes.

Columbia River and estuary

J. L. Glenn observed that concentrations of radionuclides and the physical, chemical, and mineral characteristics of suspended particulate materials from the Columbia River estuary exhibited variations that coincided with changes in seasonal upland flows and diurnal tidal flows. Although seasonal and tidal trends in physical, chemical, and mineral characteristics are generally similar to, and compatible with, trends in radionuclide concentrations, deviations may be observed when suspended materials are derived from the bed and banks of the estuary and from the tributaries that enter the Columbia River near the estuary. Particle-size distributions and radionuclide concentrations in multiple sets of bottom-sediment samples, collected over a 2½-yr period from four environments in the Columbia River, varied with time. Temporal variations of particle size were grossly relatable to changes in upland flows of the Columbia River. Temporal variations of radionuclide concentrations reflected textural changes and the general decrease in radionuclide levels that resulted from shutdown of some reactors during the sampling period.

Instantaneous discharges in the Columbia River estuary at Astoria, Oreg., where the flow is affected by salinity gradients, have been determined on a continuous basis by G. A. Lutz, H. H. Stevens, Jr., and D. W. Hubbell through the application of a modified version of a one-dimensional, homogeneous-density, transient-flow model. Modifications include varying η, the resistance coefficient, throughout the tidal cycle to produce hydrographs having the correct shapes and applying a water-surface slope correction each day to yield discharges having the proper mean daily value, which can be determined from a knowledge of the flow and storage upstream. Discharge data

are required to determine rates of radionuclide transport in the estuary.

Effects of radioactive- and chemical-waste disposal, National Reactor Testing Station, Idaho

Evaluation of the long-term subsurface influence of liquid radioactive- and chemical-waste disposal at the NRTS (National Reactor Testing Station) was completed by J. B. Robertson, Robert Schoen, and J. T. Barraclough. The influence of 18 yr of waste disposal on the hydrogeochemistry of Idaho's Snake River Plain aquifer was analyzed. The geologic origin and structure of the Snake River Plain was reinterpreted in relation to the hydrogeochemistry of the aquifer. The natural ground-water chemistry is influenced more by the rocks of the surrounding valleys than by rocks within the plain. The principal wastes discharged to the aquifer include sodium chloride, chromates, tritium, strontium-90, cesium-137, and heat. Hydraulic dispersion is exceptionally effective in spreading and diluting the waste in the aquifer. Sorption has greatly retarded the migration of cationic strontium-90 and cesium-137. Some wastes have migrated 5 mi south in the aquifer, but none have yet approached the NRTS boundary. The NRTS had only a small localized influence on the total quantity and quality of the aquifer water. This study provided data for a developmental mathematical model of solute transport in the aquifer. Initial phases of the digital hydraulic modeling have been completed.

Influence of geologic and hydrologic factors upon migration of radionuclides from solid-waste burial ground, National Reactor Testing Station, Idaho

Drilling, sampling, and testing are being done to determine the extent of any radionuclide migration and the hydrogeologic and other influences on such movement. Four cable-tool exploration-observation wells, outside of the NRTS solid-waste burial ground, have been completed at depths of 640 ft or 55 ft below the water table of the Snake River basalt aquifer. Locally, the hydraulic gradient, as compared to the regional gradient, is reversed. Chemical and radiometric tests of the basalts, interbedded sediments, and ground water show no contamination. Stratigraphic correlations by Coyd Yost, Jr., show that 25 to 50 ft of fine, unconsolidated sediments, contained in as many as five strata, may extend under the burial ground, where the sediments may act as important retardants to downward migration of radionuclides toward the water table. Individual basalt sequences have been identified in each well, and correlated between wells, on the basis of characteristic natural radiation shown by gamma logs. The upper surfaces of these basalt sequences are the ancient land surfaces upon which paleosols were deposited. Within the burial ground, core drilling to the second sediment at a depth of 250 ft has begun. The geomorphology and petrographic characteristics of the surface sediments, in which the waste pits and trenches are dug, indicate that much of the finer material is of aeolian origin, whereas interfingered coarser material is of fluvial origin. Some layers of very clayey material apparently originated in intermittent playa ponds or small lakes. The finer surficial sediments, because of higher ion exchange and lower permeability, are more likely to retard radionuclide movement.

Hydraulic fracturing and grout injection

G. H. Chase reported that interpretation of field-test results and theoretical analyses indicated that factors of anisotropy may be utilized to aid in predicting, establishing, and maintaining low-angle attitudes of hydraulically-induced fractures in shale at moderate depths. Ratios of values for elastic parameters and for other physical and hydrologic properties measured normal to bedding versus those measured parallel to bedding show a large difference. Asymmetric topographic loading and structural factors may superimpose a second set of anisotropic factors upon those of shale groundmass characteristics. Operational practices can apparently be adjusted to allow for differences in injection-fluid characteristics and for distinctive geologic and hydrologic features of the local environment, unless vertical discontinuities in the shales are too large and extensive or unless the rocks are under excessively large directional tectonic stresses.

SITES FOR NUCLEAR POWER REACTORS AND OTHER FACILITIES

The USGS has continued its reviews of geologic and hydrologic aspects of license applications to the U.S. Atomic Energy Commission for nuclear facilities such as power reactors, fuel-processing plants, and solid-waste burial grounds. These reviews evaluate geologic and hydrologic phenomena which are related to the safety of the facility, such as faulting due to seismic activity, flooding, availability of water for cooling, and foundation conditions, as well as the potential extent of contamination of water resources that could occur through the operational or accidental release of radionuclides. The reviews result in reports to the Atomic Energy Commission which are included in the public record of the licensing proceedings before the Atomic Energy Commission.

During the year, E. H. Baltz, Jr., F. A. Kilpatrick, and H. H. Waldron prepared reviews of the geologic and hydrologic aspects of sites for 29 proposed nuclear powerplants.

In connection with studies for proposed reactor sites, H. C. Wagner and Arne Junger collected geophysical data offshore near San Clemente, Calif. Interpretations of the data revealed a zone (about 7 km offshore) of discontinuous folding and faulting that roughly parallels the coastline. The location and trend of the offshore zone suggests that it may be a southeastern extension of the onshore Newport-Inglewood zone of historically active seismicity.

FLOODS

Three major categories in the study of floods by the USGS are (1) measurement of stage and discharge, (2) definition of the relation between the magnitude of floods and their frequency of occurrence, and (3) delineation of the extent of inundation of flood plains by specific floods or by floods having specific recurrence intervals. The following discussion is divided into the categories of outstanding floods, flood-frequency studies, and flood mapping.

OUTSTANDING FLOODS

Floods of May and June 1971 in western Nebraska

A storm that centered over the central Rocky Mountains during the period April 18–26, 1971, caused heavy snowfall with a water equivalent of 1 to 4 in. over most of Wyoming and western Nebraska. Rains exceeding 3 in. occurred on May 5 over the same area. According to F. B. Shaffer, the combined effect of the two storms produced maximum flows into Glendo and Guernsey Reservoirs and flood flows on the Laramie River. The series of large reservoirs in Wyoming which normally withhold all snowmelt runoff were filled and the combined effect of filled reservoirs and heavy rainfall produced unprecedented prolonged flooding conditions. These conditions continued well into June in western Nebraska.

Flood damage was relatively small and confined principally to pastureland, hay meadows, bridge approaches, basements, and backup in sewers.

Record-breaking floods in northeastern Nebraska, February 18–19 and June 4–10, 1971

F. B. Shaffer reported that severe thunderstorms on February 18–19, 1971, caused extensive flooding in the Logan Creek and Elkhorn River basins in northeastern Nebraska. Rainfall in amounts of 3 in. was general throughout the area, and because the ground was frozen during the 2-day period of heavy rainfall, runoff was abnormally heavy.

The flood caused much damage to highways and railroads along the North Fork Elkhorn River above the city of Norfolk. Flooding also occurred along the Elkhorn River between Norfolk and the river's mouth. Nineteen counties were declared disaster areas, and damage claims totaled more than $1.5 million.

On June 4–10, 1971, heavy rains occurred again over much of the same area, causing a return of severe flooding in some places. Damage claims totaled more than $350,000.

Summer floods of 1971 in south-central Alaska

Precipitation of from 3 to 9 in. during August 5–11, 1971, combined with antecedent conditions of above-average snow cover and prior rains, caused damaging floods in south-central Alaska. R. D. Lamke reported that the flooding was most severe in the Matanuska Valley near Palmer, with magnitudes of peak discharges from 1.2 to 23.4 times the discharges of the 50-yr flood. Flood damage during August was estimated at $8 to 10 million. Prior flooding from snowmelt occurred at scattered sites throughout the area from the Copper River basin to the Kuskokwim River basin.

Floods of August and September 1971 in New Jersey

S. J. Stankowski reported that intense thunderstorm activity on August 26–27, followed by the passage of tropical-storm Doria on August 27–28, resulted in severe flooding in streams in south-central, central, and northeastern New Jersey. As much as 9.7 in. of rain fell in 24 hr producing peak flows throughout the flood area greater than any previously experienced at 47 stream-gaging stations. On September 11–14, 1971, intermittent heavy thunderstorm activity yielded up to 9.1 in. of rainfall in northeastern New Jersey. Peak flows greater than any previously known were recorded at eight stream-gaging stations. These two flood events caused the loss of at least four lives and direct property damage estimated at more than $140 million.

FLOOD-FREQUENCY STUDIES

Special gage network designed for flood program in Marion County, Florida

A county-wide study of flood potential in Marion County will require 300 to 500 crest-stage gages and 250 crest-stage wells to determine annual peak stages of surface water and the ground-water table. Warren Anderson reported that this number of gages is necessary because the karst terrane in the county contains many isolated lakes, ponds, and sinks. The annual peaks recorded by these gages will be correlated with peaks obtained by long-term gages to evaluate their frequency of occurrence. The final results are intended for use in decisions related to flood-plain zoning, septic-tank permits, and highway design.

Small-area flood hydrology in Georgia

Available flood information has been analyzed to provide planners and designers with preliminary relations for estimating the magnitude of flood-peak discharges on small streams in Georgia. The relations were defined by regional regression analyses of flood records for 224 sites, 104 of which are records for small streams that have not been used previously in regional frequency analyses. Discharge estimates based on these preliminary relations require determination of watershed size from topographic maps or aerial photographs, precipitation intensity, and soil indices. According to H. G. Golden, the estimating relations may be used for any site in Georgia where the drainage area ranges between 0.1 and 20 sq mi and where

the floodflow is virtually natural.

Flood-frequency study in Illinois

J. M. Carns reported that a statistical analysis of flood peaks on unregulated streams in Illinois indicated that the three major independent variables that affect flood-frequency relations for Illinois streams are drainage-area size, slope of the stream, and the 2-yr, 24 hr rainfall intensity. The report gives equations which can be used to estimate recurrence intervals ranging from 1.25 to 100 yr.

Flood-frequency methods analyzed for Iowa

A comparative study of regional flood-frequency methods was conducted by O. G. Lara to evaluate results obtained by applying four methods of analysis to flood-discharge data collected in Iowa.

The methods selected for study were (1) index-flood method, (2) multiple correlation method, (3) correlation of log-Pearson type III parameters, and (4) correlation of log-normal parameters. Of the methods tested, the multiple correlation method proved to be the most reliable. This conclusion was reached by observing the relative ability of each method to reproduce the base data. The method of correlating the log-Pearson type III parameters was slightly less reliable. The residual errors associated with the index-flood method and the log-normal method were much larger.

On the basis of conclusions from the study, the Iowa Natural Resources Council, in cooperation with the USGS, is preparing a manual which will present techniques and procedures for estimating the probable magnitude and frequency of floods on Iowa streams. The estimating equations to be included in this manual are based on regional relations between floods of specific return periods and selected basin characteristics. Drainage-area size and main-channel slope were found to be the most important factors that influence flood peaks in Iowa. Two hydrologic regions were defined. Region 1, the largest, covers about 68 percent of the land surface of Iowa. Region 2 covers most of the area which is known as the Des Moines lobe. Mathematical relations which relate floods of selected recurrence intervals to basin parameters within each region were defined.

Flood-flow characteristics of small drainage basins in Massachusetts and Vermont

Results of a continuing study by C. G. Johnson and G. A. Laraway to develop a technique for estimating the magnitude and frequency of floods on small drainage areas in Massachusetts and Vermont indicate that regression relations previously developed from long-term data for a streamflow-evaluation study may be used to estimate the long-term 2-yr peak flow on small streams.

Flood-frequency relationship for small basins in Virginia

E. M. Miller is conducting a study to estimate magnitudes and frequencies of floods on small streams in Virginia. Flood-hydrograph recorders (type SR) are used to collect stage and rainfall records at approximately 100 sites. Using the rainfall-runoff model, data from small-stream basins will be modeled, and National Weather Service rainfall records will be used to generate peak discharges, thus extending records back in time. Extended records will define longer periods on which to develop flood-frequency relationships for small drainage areas. A 5-yr progress report presented preliminary flood-frequency relations for estimating the magnitudes and frequencies of floods on streams with drainage areas of 20 sq mi or less.

FLOOD MAPPING

Channel capacity of the Feather River between Oroville and Honcut Creek, California

J. C. Blodgett and R. G. Simpson evaluated the adequacy of a 22-mi reach of the Feather River between the town of Oroville and Honcut Creek to convey the design flood release of 150,000 cfs downstream from Oroville Dam. Surveys indicated that the channel has scoured as much as 5.8 ft and that the cross sectional area has increased up to 350 percent at selected locations during the period 1909–70. This scour has the effect of increasing the capacity of the channel to convey floodflows.

Prior to construction of Oroville Dam, peak flows decreased as much as 23 percent as floods traversed the study reach. Under present conditions, peak discharges in the study reach are altered by upstream regulations, inflows up to 21,600 cfs from Thermalito Afterbay, and storage in large impoundment basins built on the flood plain, as well as storage in natural channels.

The adequacy of the existing channel was investigated for discharges ranging from 40,000 to 160,000 cfs. Computed water-surface elevations indicate that discharges up to 68,000 cfs will be contained within the natural and leveed channel for most of the study reach. Higher discharges will cause overbank flooding on the left-bank flood plain in the lower one-third of the reach.

Backwater effect from Thermalito Afterbay inflow will increase stages up to 3.4 ft on the Feather River, and the effect may extend as far as 3.5 mi upstream.

Channel capacity of part of Mokelumne River, California

The adequacy of a 39-mi reach of the Mokelumne River to carry flood releases from Camanche Reservoir is described in a channel-capacity report being prepared by R. G. Simpson. Maps, profiles, cross sections, and stage-discharge relations indicate the extent of flooding that has occurred and that may

be expected to occur in the future from a design flood release of 5,000 cfs. Data in the report will be useful for defining the primary floodway and for minimizing vulnerability to flood damage.

Channel capacity of part of San Joaquin River, California

The adequacy of a 53.1 mi reach of the San Joaquin River downstream from the Merced River confluence to carry flood-flows is described in a channel-capacity report being prepared by R. G. Simpson. Maps, profiles, cross sections, and stage-discharge relations indicate the extent of flooding that occurred in January–February 1969 and that may be expected to occur in the future from floodflows up to 60,000 cfs. Data presented in the report will be useful for defining the primary floodway, for evaluating the effects of future levee construction, and for minimizing vulnerability to flood damage.

Hydrograph model of the Hillsborough River basin, Florida

J. F. Turner, Jr., reported that computed profiles were generated for selected floods (recurrence intervals of 2, 5, 10, 25, 50, 100, and 200 yr) for more than 10 mi of the main stem of the Hillsborough River. Highly urbanized northeast Tampa and the subdivision Temple Terrace are included in the area studied. Stream cross-section data used in computing the profiles were furnished by the U.S. Corps of Engineers, Jacksonville, Fla. Roughness coefficients were based on those available from the Corps and on discharge measurements made at points along the study reach. Adjustments of the roughness coefficients were based on data obtained for a flood that occurred during March 1960. The profiles will be used in developing flood maps of the study reach.

Flood maps of Lansing, Marquette, and McGregor, Iowa

Water-surface contours and areas inundated by the 100-yr flood at Lansing, Marquette, and McGregor, in northeastern Iowa, were delineated on maps by O. G. Lara. The information will be applied to land-use management as a basis for establishing flood-insurance rates.

Flood profiles of streams in Iowa

Water-surface profiles and discharges for floods on 230 mi of streams in the Iowa River basin were determined by A. J. Heinitz. The streams include the East and West Branches of the Iowa River downstream from U.S. Highway 18 near Garner and Britt, respectively, and the main stem of the Iowa River between State Highway 149 near the Amanas and the confluence of the East and West Branches at Belmond. Profiles of several outstanding floods were obtained from field surveys, and profiles of the 25- and 50-yr floods were computed. Tabulations of stage and discharge for selected floods at gaging stations provide data for plotting hydrographs.

Flood-plain study of lower Minnesota River, Minnesota

Hydrologic and hydraulic aspects of the lower Minnesota River pertaining to its flood plain between Carver Rapids and the river's mouth are being studied by L. C. Guetzkow and G. H. Carlson. The flood plain of the Minnesota River in the 35-mi reach under study is broad and flat and has undergone considerable flood damage in the past. Availability of river-barge transportation in the valley and the area's proximity to the Twin City metropolitan center has created much pressure for industrial development on the flood plain. The study identifies the flood-hazard areas and evaluates the effects of the proposed development on the flood plain. The results will be used as a basis for basin planning and for flood-plain zoning ordinances.

Orthophotomapping for use in flood-plain zoning studies

E. A. Oster and D. D. Harris are conducting flood-profile studies of the Umpqua River basin in Oregon. Orthophotomaps (rectified aerial-photograph images) at a scale of 1:4,800 show land-surface contours at 5-ft intervals and channel cross-section elevations at about 1,000 ft intervals along the channel. Included with the maps are digital cards with ground elevations punched for every 100-ft interval along each cross-section line. The maps and cards are used to develop flood profiles and to delineate flood boundaries for land-use management purposes.

Flood-inundation mapping in Fairfax County, Virginia

In cooperation with Fairfax County, Va., P. L. Soule and other USGS scientists are studying the effects of urbanization on floodflows. Results indicate that urbanization may increase average floodflows up to eight times that of floodflow in a natural basin.

Flood plains of streams draining areas greater than 1 sq mi are shown on large-scale (1:1,200) maps, and areas of floods having recurrence intervals of 25-, 50-, and 100-yr under projected conditions of ultimate urban development are being delineated. In the past year, 149 flood maps of four streams (72.1 linear mi) were prepared; to date 11 streams (180 linear mi) in Fairfax County have been mapped.

The flood-plain maps and the flood-profile information provided by the Fairfax project are being used by the county in its analyses of land uses and review of plans for development.

Maps of flood-prone areas

Areas inundated by the 100-yr flood are outlined on topographic maps as part of the national program for managing flood losses. The objective of this activity is to

inform cities and towns of the general extent of their potential flood problems. More than 4,000 such maps (1,139 in fiscal year 1972) have been completed in 46 States.

Inundation maps of urban areas

Maps (single sheets, scale 1:24,000, with text) showing areas inundated by major floods, flood profiles, discharge-frequency relations, and stage-frequency relations were published as hydrologic investigations atlases for the following areas: Wilmington, Ill., by H. E. Allen and A. W. Noehre (1971); Carpenteria, Calif., by F. W. Fenzel and McGlone Price (1971); Azusa and Glendora, Calif., by F. W. Giessner and McGlone Price (1971); Douglas County, Oreg., by E. A. Oster (1971); Cucamonga, Calif., by J. A. Singer and McGlone Price (1971a); and Ventura, Calif., by J. A. Singer and McGlone Price (1971b).

WATER QUALITY AND CONTAMINATION

The development and use of water in many areas are restricted or complicated by the presence of undesirable waste products and natural constituents in surface and ground waters. To study these undesirable water contaminants, the USGS conducts basic research and areal investigations that define the causes and the extent of contamination in the environment.

Mine drainage

From the interpretation of water-quality data for underground coal mines in western Maryland, E. F. Hollyday and S. W. McKenzie concluded that at least half of the total acid generated is neutralized naturally in the mine before being discharged at the surface. Of the 18 sites studied, 13 exhibited significant reductions in the amount of acid discharged as compared to the amount generated (based on equivalents of residual sulfate). At sites where ground water moves from an upper mine level through intervening rock strata to a lower mine level, at least four-fifths of the total acid generated is neutralized in the underground environment before the water reaches surface streams.

In Colorado, D. A. Wentz located 37 streams where water quality appears to be adversely affected by drainage from mineral deposits or from metal mining and milling operations. Field observations of pH, specific conductance, aquatic biota, and condition of stream bottom and water were used to locate these streams. Field pH values as low as 3.0 and specific-conductance values as high as 2,600 μmhos/cm were observed. Effects on aquatic biota ranged from total exclusion to changes in species diversity and population density.

Within the 70 percent of the laboratory analyses that are completed, 8 percent of the samples contained cadmium concentrations greater than the limits recommended in the drinking-water standards of the USPHS. Manganese and iron exceeded specific limits in 47 and 13 percent of the samples, respectively. Lead and mercury exceeded the limits in only 2 percent of the samples. Arsenic and selenium concentrations were not found in excess of acceptable limits, and chromium and silver were not detected.

Pesticides in water and sediment

Monitoring of pesticides at 20 stations on streams in the Western United States was continued during the period October 1970 to September 1971. In studies reported by J. A. Schulze, D. B. Manigold, and F. L. Andrews, herbicides, principally 2,4-D and 2,4,5-T, were found more frequently and in higher concentrations than in previous years. DDT and its degradation products accounted for about 80 percent of all insecticide occurrences, but insecticides containing phosphorus were found with increasing frequency. Most of the chlorinated-insecticide load carried by streams is associated with suspended material.

The distribution of chlorinated-hydrocarbon insecticides and PCB in bottom sediments of various sizes was studied by D. F. Goerlitz and L. M. Law. Contaminated samples of bed material were sized into gravel, sand, silt, and clay fractions by standard sieving, settling, and centrifuging techniques. The identities of the various chlorinated compounds present were verified by gas chromatography–mass spectrometry. No strong relationship between pesticides and size of sediment was apparent. Rather, the pesticides appear to be associated with organic matter and benthic organisms.

Sixteen recreation lakes in Pennsylvania were sampled for trace elements in the water and common chlorinated-hydrocarbon pesticides plus PCB in the lake sediments, as part of a study by J. L. Barker. Nine of the lakes contained concentrations of cadmium in excess of USPHS drinking-water standards, and one contained concentrations potentially harmful to fish and other aquatic life. DDT in five lakes, DDD in three lakes, and chlordane in five lakes were in excess of concentrations potentially toxic to fish-food organisms.

The pesticides were found to range from 0 to 42 μg/kg DDT, 1.5 to 32 μg/kg DDE, 1.7 to 290 μg/kg DDD, 0 to 1.1 μg/kg dieldrin, 0 to 40 μg/kg chlordane, and 0 to 50 μg/kg PCB. Aldrin, endrin, heptachlor, and lindane were not detected.

Minor elements in water and sediment

A reconnaissance study of the Skaggs Springs area, Sonoma County, Calif., has been undertaken by W. G. Hines (1971) to determine the water-quality hazard that may result from flooding of an abandoned metacinnabar (mercury ore) mine and three associated hot springs. The mine and hot springs will be inundated in the mid-1970's by Lake Sonoma, an artifical multipurpose lake to be formed behind Warm Springs Dam (U.S. Army Corps of Engineers project). Results as of

February 1972 indicate low concentrations of mercury in tailings near the mine (14 ppm) and in water in the nearby hot springs (<0.05 to 1.8 μg/l in unfiltered samples). Mercury concentrations in the bottom sediment of the spring pools and in thermophilic algae range from 0.8 to 180 ppb on a dry-weight basis. The observed concentration factors for mercury in algae are some of the highest ever noted.

G. L. Feder found that bottom muds in a water-supply lake in Missouri contain high levels of potentially toxic trace elements. The bottom mud in the study lake contained 0.12 ppm mercury, 0.7 ppm selenium, and 11 ppm arsenic. The high trace-element levels in the bottom mud are reflected in the trace-element content of the water near the bottom of the lake (total depth, 22 ft). The mercury, selenium, and arsenic content of the water 3 ft above the bottom was 0.005, 0.028, and 0.006 mg/l, respectively. The water near the top of the lake had the lowest trace-element content, 0.008 mg/l selenium, and no detectable mercury or arsenic.

H. B. Wilder investigated the occurrence and transport of arsenic in the Sugar Creek watershed in the vicinity of Charlotte, N.C. An arsenic concentration of 1,100 μg/l was found at Sugar Creek near Fort Mill, S.C., in October 1970; the source was effluent from a sewage treatment plant in the city of Charlotte. Additional study of unfiltered stream water in June and July 1971 showed that concentrations as great as 250 μg/l were still being discharged by the treatment plant (the load ranged from 9.3–17.3 lb per day of arsenic).

Concentrations of arsenic as great as 35,000 ppb, which were found in bed materials taken from the bottoms of Irwin and Sugar Creeks, indicate that arsenic was concentrating in the solid bed materials. Solid material in the treated-sewage effluent reached a maximum concentration of 500,000 ppb.

During a flood on Sugar Creek near Fort Mill, S.C., in July 1971, arsenic loads as great as 480 lb per day were measured—seemingly reflecting a pickup of arsenic, which had been concentrated in the streambed during the preceding low-flow period. Analyses of data collected during the flood showed that total arsenic loads correlated quite closely with total suspended-sediment loads, a correlation which further confirms the conclusion that most of the arsenic was being transported in the suspended-sediment phase of the system.

J. D. Hem reported that solubilities of lead carbonate and hydroxide were only a few micrograms per liter in solutions containing more than about 61 mg/l of bicarbonate and near or above pH 8.0 but increased rapidly with decreasing pH or bicarbonate. Relatively dilute water with a pH of less than 7.0 thus might retain concentrations substantially greater than the drinking-water standard limit of 50 μg/l. Runoff of this type from thickly populated regions in the Eastern United States may contain undesirable concentrations of lead introduced into the environment by combustion of leaded gasoline. Simple carbonate or hydroxide solubility controls of zinc and cadmium (Hem, 1972) appear unlikely to influence concentrations of these two elements in most river water. Cadmium may be present in undersirable concentrations in some of the same areas where lead concentrations are high.

Nutrients in water

According to J. M. Klein and P. A. Emery, the nitrate concentration in water from the unconfined aquifer in the San Luis Valley, Colo., exceeds recommended health standards throughout an area of about 70 sq mi. Nitrate concentration ranges from 30 to 138 mg/l in ground water in the west-central part of the valley; these high values probably result from heavy applications of chemical fertilizers.

In a study of the shallow ground water in Kings County, N.Y., G. E. Kimmel found that the nitrate content was greater than that of the native ground water elsewhere on Long Island. Nitrate nitrogen concentration was locally as much as 30 mg/l. The high nitrogen content was attributed to leakage from sewers.

Nitrogen compounds, particularly nitrate, are the principal contaminants in ground water in Long Island, N.Y., and have made the upper glacial aquifer in most of Nassau County and in parts of Suffolk County unfit as a source of water for public supply, according to C. A. Harr (1971). In addition, a large part of the underlying Magothy aquifer and a small part of the deeper Lloyd aquifer in the northern part of Nassau County have become contaminated. The generally higher average content of nitrogen compounds in ground water in the more populous Nassau County, as compared with Suffolk County, is attributed to the disposal of larger amounts of sewage into cesspools and septic tanks. Streams draining rural areas normally have lower concentrations of nutrients than those draining urban areas.

Bacterial contamination of ground water

Water from nearly 1,800 commercial, farm, and domestic wells in the Niagara dolomite in Door County was tested for coliform bacteria between May and September 1971 by the Wisconsin State Laboratory of Hygiene. Almost 19 percent of these water supplies were found to be bacterially unsafe for human consumption. M. G. Sherrill believes the following factors are most responsible for contamination of the ground water: (1) A well-developed vertical and bedding-plane joint system, which allows easy entry and movement of water and associated contaminants from the surface, (2) thin unconsolidated cover over bedrock, (3) inadequate spacing of individual or groups of wells and disposal sites or systems, and (4) inadequate construction of the older wells and disposal systems.

J. H. Barks is documenting the bacteriology of selected large springs in the Ozark region of Missouri. Total coliform bacteria were found in all the springs sampled, and most of the springs contained some fecal coliform and fecal streptococci, which are indicators of the possible presence of disease-producing organisms. Significant numbers of all three types of bacteria were found in some springs that are commonly used for

drinking water. Three springs believed to have the same recharge area had high counts; other springs with different recharge areas in the same part of the State had low counts. Preliminary studies indicate that the sources are sewage discharges, sewage lagoons, and sinkholes used as refuse dumps in the recharge areas.

Probability distribution of BOD and DO

I. I. Esen (Colorado State Univ.) and J. P. Bennett (1971) along with R. E. Rathbun (both USGS) developed a random walk model to predict the probability distribution of the BOD and used a Monte Carlo technique to predict the probability distribution of the DO for a system in which the reaeration and deoxygenation coefficients are considered as random variables. This model permits the estimation of the variance and confidence limits as well as the mean value of the DO concentration at points downstream from waste sources.

Waste assimilation in Pearl River, Louisiana

Municipal waste from the city of Bogalusa, La., and industrial waste from papermill effluent are the principal sources of pollution in the Pearl River downstream from Bogalusa. Although the Pearl River has an average flow of 8,500 cfs, the river cannot assimilate the present waste load when warm weather and low flows occur simultaneously, according to D. E. Everett.

An average BOD waste of approximately 30 tons per day is discharged into the Pearl River. The effects of this waste load on DO levels is significant during the summer when river discharge is less than 3,000 cfs. At times, the DO concentration at Pools Bluff, 9 mi downstream from the waste outfall, has been less than 2.0 mg/l. However, at a discharge of 8,000 cfs or greater, the waste is sufficiently diluted and has very little effect on oxygen levels in the river.

Domestic sewage discharged into the river causes high bacterial concentrations. At Pools Bluff, concentrations of fecal coliform ranged from 540 to 3,300 colonies per 100 ml. Downstream from Pools Bluff, bacteria die at a constant rate, and after 24 hr the residual population is about 16 percent.

A mathematical model has been developed to predict the effect of biodegradable-waste loading on the oxygen balance in the river when the discharge is less than 6,000 cfs.

Hurricanes cause deterioration in water quality in New Jersey

A deterioration in water quality was observed on two major streams in New Jersey during the high flows associated with Hurricanes Doria and Heidi in August and September 1971, according to F. L. Schaefer. For the Delaware River at Trenton, daily average DO content dropped from 8.7 mg/l on August 26 just prior to the first storm to 5.9 mg/l on September 1. The second storm lowered the average DO concentration from 8.1 mg/l on September 8 to 4.3 mg/l on September 12. The 4.1 mg/l of DO observed on September 12 was a new low for the 10 yr of record. Also, the average pH decreased significantly from 8.2 on September 10 to 6.5 on September 13.

Substantial decreases in DO and pH also were noted in the tidal reach of Rancocas Creek. Minimum DO decreased from 4.2 mg/l on August 26 to 1.6 mg/l on September 1, then varied from about 1.0 to 2.0 mg/l until September 14 when a minimum of 0.5 mg/l was reached. It should be noted that DO concentrations of less than 1.0 mg/l were recorded during several other rainy periods from June to August 1971. Similarly, pH, which had not fallen below 5.8 during any summer day prior to Hurricane Doria, dropped to 4.9 on August 28 and to 5.0 on September 15.

The degradation of water quality at these two stations is believed to have resulted from a combination of the following factors: prolonged cloudy periods normally associated with major storms; restricted photosynthesis; highly turbid water caused by storm runoff; and, in the case of the pH decline in Rancocas Creek, the flushing downstream of marsh and swamp water of low pH.

Evaluation of spraying sewage effluent

R. C. Reichenbaugh reported that the spray application of 25,000 gpd of secondary-treated chlorinated sewage effluent to 30 acres of pasture in central Florida caused only minor changes in water quality in the surficial fine acid-sand aquifer. The chlorinated effluent has an average BOD of about 40 mg/l and a dissolved-solids content of 450 mg/l; the principal nitrogen specie is nitrate. The water table in the shallow aquifer is 2 to 8 ft beneath the pasture, and the principal nitrogen species in the ground water are ammonia and organic nitrogen. Neither fecal coliform nor fecal streptococci has been detected in the ground water.

Contamination of canals in Florida

The Miami River-Canal in Dade County, Fla., was sampled in March and September 1971 to provide data that could be used in guiding efforts to clean up the Miami River, according to F. W. Meyer and E. T. Wimberly. Observations of water and sediment at 11 sites along the reach from Biscayne Bay to conservation area 3 (a distance of 20 mi) indicated that the quality of water upstream of the salinity control was generally acceptable for public surface-water supplies except for a few constituents. Pesticides occurred in surface water at only three sites but were present in the sediment in most places. Coliform organisms were found in all surface-water samples. PCB was found in sediment at six sites and in aquatic biota at one site.

Studies by C. B. Sherwood and H. J. McCoy indicated that contamination by urban wastes is a major threat to the water resources of Broward County, Fla., because of the controlled canal network and the development of water supplies from the highly permeable shallow aquifer. The chief contaminants are

derived from treated sewage effluent discharged into the canal system. Although concentrations of contaminants in most canals in the system are relatively low, samples from some canals with little or no perennial flow have contained in excess of 40 mg/l of phosphates and ammonium and little or no DO.

Subsurface waste injection

Extensive areas of Florida are underlain by permeable saline-aquifer systems. Acidic, high oxygen-demand industrial wastes and treated municipal effluents are injected into subsurface environments at depths ranging from 1,400 to 3,000 ft, according to M. I. Kaufman. Transmissivities of the receiving carbonate aquifers range from 6,500 gpd per ft in northwestern Florida to more than 17 mgd per ft for the cavernous Boulder Zone in southern Florida. Over 7 billion gal of waste have been injected through mid-1971. Observed effects include (1) increased hydraulic heads and formation pressures with pressure effects extending over broad areas, (2) reversal of natural hydraulic gradients and establishment of a potential for updip migration; (3) significant increases in injection index, dissolution of the carbonate aquifer, and localized cavern development beneath injection sites, and (4) neutralization of acidic wastes, anaerobic decomposition, denitrification, sulfate reduction, and evolution of high concentrations of hydrogen sulfide, nitrogen, methane, and other gases.

Since 1963 more than 4 billion gal of acidic industrial waste has been injected into a saline limestone aquifer near Pensacola, Fla. This aquifer is overlain by an extensive confining bed of clay, which is 200 ft thick at the injection site. The waste, an aqueous solution containing organic acids, nitric acid, inorganic salts, and numerous organic compounds, is injected into the aquifer through two wells 1,300 ft apart between depths of 1,400 and 1,700 ft. The pH of the injected solution is about 2.5. Wellhead injection pressures were about 200 psi but have decreased to 175 psi even though injection rates have increased from 1,600 to 2,000 gpm.

In November 1971, D. A. Goolsby, M. I. Kaufman, and C. A. Pascale conducted a 4-day backflushing experiment in the Pensacola test area and found that waste fluids (7.5 million gal) backflushed during the experiment had very little contact with the limestone in the injection zone. The pH, which was monitored continuously increased from 2.5 to 3.4. Field determinations indicated that a relatively small quantity of calcium was present in the backflushed fluid. Denitrification was not detected. Some evolution of gas was observed, and a partial analysis showed that nitrous oxide, carbon dioxide, nitric oxide, and methane accounted for about 75 percent of the gas.

Ground-water contamination is likely to occur because of the rapidly expanding practice of onsite subsurface waste disposal in Hawaii, according to K. J. Takasaki. Most of the waste is raw or partly treated domestic sewage effluent. Where the underlying ground water into which the waste is injected is shallow and brackish, as it is in most coastal areas, contamination of the ground-water body has been of no real concern to public officials. Where the receiving ground water is fresh and of domestic quality inland from coastal areas, the likely contamination of the ground-water body from the waste of existing and planned developments is becoming a major concern. So far, no public or private water-supply source has been known to be polluted and rendered useless by injected waste. The major problem in coastal areas is the overflow of sewage effluent from inadequately designed seepage trenches and wells which causes contamination of the ground and beach areas.

Contamination resulting from solid-waste disposal

G. E. Kimmel, Ellis Koch, and E. C. Rhodehamel found a plume of contaminated ground water downgradient from a solid-waste disposal site in southwestern Suffolk County, Long Island, N.Y. The plume is in the highly permeable upper glacial aquifer (hydaulic conductivity about 2,000 gpd per ft^2). The specific conductance in the plume is 2 to 25 times greater than the background specific conductance of the surrounding ground water and extends at least 8,000 ft from the 25-yr-old disposal site. The bottom of the disposal pit is at the water table. The plume ranges in depth from the water table to about 90 ft below the water table.

A sanitary-landfill operation in the city of Fort Myers, Fla., has contaminated the water-table aquifer. According to D. H. Boggess, chemical data for water from a contaminated well compared to water from a control well show the following: iron and calcium content, nearly two times greater; magnesium, organic nitrogen, and dissolved-solids content, nearly three times greater; sodium and chloride content, six to seven times greater; and sulfate and ammonia content, eight to 10 times greater.

A study of two active and two inactive landfill sites in Hillsborough County, Fla., was continued in 1971 by J. W. Stewart and A. D. Duerr to determine the effects on the water resource of disposing of solid wastes in surficial material where a high water table occurs. All sites being investigated are underlain by a highly permeable limestone aquifer. At completed landfill sities 7 to 10 yr old, hardness and concentrations of chloride, sodium, calcium, potassium, and iron in water in the shallow water-table aquifer were as much as 2 to 70 times greater than background levels. At the active landfill sites that have been in operation for 2 yr, slight increases in conductivity, hardness, chloride, and iron were observed in wells near completed trenches and near a perimeter canal downgradient from the disposal sites. No noticeable changes in the chemical quality of the water in the limestone aquifer have been observed to date at either the completed or active landfill sites.

Deterioration of ground water in Lompoc Plain, California

G. A. Miller reported that ground water beneath much of the Lompoc Plain, in western Santa Barbara County, Calif., has deteriorated significantly in quality, owing to irrigation practices and sewage discharge from several sources. The dissolved-solids content has increased in some areas from the range of 500 to 700 mg/l during the 1930's to more than 1,500 mg/l during 1970–71. Chloride content has increased locally from the range of 80 to 100 mg/l during the 1930's to more than 300 mg/l during 1970–71.

Radioactivity

The Radiochemical Surveillance Network of the USGS, which obtains data on the background level of radioactivity in the surface waters of the conterminous United States, was expanded to 53 sites in 1971. Some preliminary results from V. J. Janzer for new locations include abnormally high values of dissolved uranium and dissolved gross alpha and gross beta radioactivity from the South Platte River at Julesburg, Colo., and the Minnesota River near Jordan, Minn. Definite sources of these abnormal values are not known. The Colorado and Missouri Rivers commonly have uranium concentrations of from 4 to 8 μg/l (well above the average uranium content of less than 1 μg/l for the Nation's surface waters). The radium content of 0.24 pCi/l for the Ouachita River at Monroe, La., is somewhat higher than the less than 0.1 pCi/l commonly found in surface waters.

A reconnaissance study of radioactivity in 14 major Alaskan rivers was started in 1971, and preliminary results show values comparable to those in surface waters of the conterminous United States. Uranium content ranges from 0.02 to 1.1 μg/l, with an average of 0.4 μg/l. Radium content has not exceeded 0.06 pCi/l.

ENVIRONMENTAL GEOCHEMISTRY

Environmental geochemistry in Missouri

A fifth semiannual progress report on the geochemical survey of Missouri was released on open file (U.S. Geological Survey, 1972). The report contains 80 maps, most on a scale of about 1:3,000,000, showing the major statewide compositional variations in bedrock, surficial geologic materials (loess and carbonate residuum), agricultural soils, uncultivated soils, and ground water. More than 30 chemical elements have been studied in each phase of the survey. One major purpose of the maps is to provide the Environmental Health Surveillance Center of the University of Missouri with information on variability in environmental character throughout the State. In addition, they provide a means whereby one can, for any purpose, determine the expected range in composition for rocks, soils, and water in any general region of the State. Maps of compositional variation in selected native vegetation and food plants are being compiled.

R. R. Tidball found that the agricultural soils of the State display a remarkably clear and well-defined pattern of variation in major element content. The pattern, closely related to the distribution of the principal soil parent material types, is reflected by aluminum, calcium, magnesium, sodium, and potassium. These elements are, by comparison, highly concentrated in the agricultural soils of the glaciated northern half of the State and of the major river valleys that contain alluvium derived from glacial deposits. Agricultural soils of the unglaciated southern part of the State, a much older landscape, contain lower concentrations. The variation pattern of silicon is complementary to that of aluminum. The patterns for minor elements, although having some similarity to the patterns displayed by the major elements, generally show high local and small regional variation over the State.

R. J. Ebens, J. A. Erdman, and G. L. Feder examined the geochemical environment within a small area in Callaway County, Mo., where metabolic disorders in beef cattle have been reported by Drs. L. A. Selby and A. A. Case, veterinarians of the University of Missouri (at Columbia). A claypit, several hundred feet across and about 60 ft deep, occurs in the upstream part of the area. A large clay pile and associated debris (limestone, coal, pyrite) lie on the margin of the pit, and runoff from the clay pile flows partly into the stream and partly into the pit where the runoff occasionally overflows into the stream. The clay and associated materials are markedly different in trace-element composition from more ordinary surficial materials in the area and throughout the State. The studies suggest that aluminum, beryllium, cobalt, copper, molybdenum, nickel, and other elements are being introduced into the local environment in anomalous amounts, and the veterinarians believe that imbalances of copper and molybdenum, and perhaps of sulfate, cobalt, and other substances in the diet may have contributed to the observed disorders in the cattle (R. J. Ebens and others, 1972).

Four Corners powerplant area

H. L. Cannon and B. M. Anderson have made an examination of the effect of particulate matter from the stacks of the Four Corners powerplant in northwest New Mexico on the chemistry of the soils within a radius of 34 mi from the plant. Barium, strontium, beryllium, and lead appear to be the most widespread contaminants, but the first three extend no more than 2 mi from the plant. Lead contamination, on the other hand, may extend for a distance of 5 mi in a westerly direction. Except for lead, the concentrations of elements in selected vegetation of the area are low in comparison with those in the same species of vegetation elsewhere.

Sampling vegetation in environmental studies

H. L. Cannon has made a quantitative study of the large

number of variables that affect sampling and analysis in trace-element investigations of vegetation. Various parts of several tree species were collected throughout the growing season. Splits of the samples were submitted consecutively for analysis immediately after collection and also in a randomized sequence at the end of the growing season. The greatest coefficient of variation—nearly 100 percent—was found in different morphological parts of the same species of tree. The variation is about 50 percent in comparable parts collected from different species and about 25 percent in the same parts of the tree collected in different seasons of the year. Variations in reported values for two splits of the same sample submitted randomly average about 15 percent. This study confirms earlier studies of the distribution of elements in vegetation and presents a quantitative comparison of the variables that may affect a plant-sampling program.

LAND SUBSIDENCE

Studies of land subsidence caused by decrease of artesian head are contributing to knowledge of the physical and hydrologic properties of leaky compressible aquifer systems, primarily through observing the response of these systems to change in applied stress.

Field measurements of compaction or expansion of sediments and the correlative change in fluid pressures can be utilized to construct stress-strain curves and derive storage and compressibility parameters, as demonstrated by F. S. Riley (1969). Field measurements of change in thickness and related stress (water-level) change in multiple-aquifer systems at several sites in subsiding areas in central California have shown that the values of the storage and compressibility parameters are one to two orders of magnitude greater when total applied stresses are in the virgin range of stressing than when they are in the elastic range of stressing, according to J. F. Poland. Hydrologists planning or interpreting aquifer tests in unconsolidated multiaquifer systems, especially in subsiding areas, should be aware of the probable tremendous increase in the numerical value of these parameters if total applied stress exceeds preconsolidation stress during any part of the aquifer test. Such changes in parameter values may lead to an erroneous interpretation of an aquifer test.

Increased importation of surface water decreases subsidence rate in Fresno County, California

Imports of surface water to the San Luis project of the U.S. Bureau of Reclamation, chiefly in western Fresno County, Calif., began in 1967 and increased from 210,000 acre-ft in 1968 to 650,000 acre-ft in 1971. These imports reduced pumpage of ground water in the project area by about 50 percent in 1971. As a result, the average artesian head of the lower (confined) zone rose 63 ft from December 1967 to December 1971; the rise was greatest in the vicinity of the California Aqueduct. According to J. F. Poland, leveling of the bench-mark net by the U.S. Coast and Geodetic Survey in 1966, 1969, and 1972 indicates that, in much of the San Luis project area, subsidence has decreased markedly since 1969. For example, a bench mark 10 mi southwest of Mendota and 1 mi east of the aqueduct subsided an average of 0.22 ft per yr from 1969 to 1972, as compared to 0.65 ft per yr from 1966 to 1969. Subsidence of another bench mark in the middle of the project reach and adjacent to the aqueduct decreased from 1 ft in 1967 (before import of surface water began), to one-quarter of a foot in 1971.

Elevation changes in the San Jacinto Valley, California

Sixteen months of extensometer records near the center of maximum subsidence in San Jacinto Valley conclusively relate land-surface elevation changes during this period to artesian-head fluctuations rather than tectonism. According to B. E. Lofgren, changes in thickness of the alluvial deposits to a depth of 1,238 ft, during both the rebound limb and the compression limb of the seasonal cycle, correlated with water-level fluctuations and equaled the net elevation changes of surface bench marks. Therefore, no compaction occurred below 1,238 ft during this period, and vertical tectonic movement was negligible. The elastic response of the aquifer system at this location was 1.6×10^{-3} ft of thickness change per foot of artesian-head change.

Subsidence in the Raymond Basin, Los Angeles County, California

Water levels in 1969 were about at their alltime low level throughout much of the Raymond Basin. Continued declines should cause effective stresses greater than during the drought years of the midthirties. Nowhere in the basin are there measurements of subsidence directly related to water-level decline. Because of the nature and thickness of the alluvial-fan deposits in the basin, however, B. E. Lofgren (1971) concluded that perhaps 0.3 to 0.5 ft of subsidence could be expected for each 100 ft of water-level decline below previous low levels. One of the proposed plans for maximum utilization of the ground-water basin calls for as much as 230 ft of additional water-level lowering in parts of the basin by the year 2020. Maximum subsidence under this pumping stress probably would be less than 1 ft and would occur so slowly and over such a broad area that it should not cause problems.

ASTROGEOLOGY

LUNAR EXPLORATION

Apollo lunar geology experiment

Two geologically significant manned missions to the moon were carried out in 1971 by NASA; Apollo 14 landed on the Fra Mauro highlands in February, and Apollo 15, on the Hadley-Apennine area in July. Data resulting from both missions were analyzed by members of the Apollo Lunar Geology Investigations Team, G. A. Swann, principal investigator. General summaries of the geology of the sites were published by Swann and others (1971) and the Apollo Lunar Geology Investigations Team (1972).

Apollo 14 provided the first direct samples of the highlands from an area interpreted as the outer part of an ejecta blanket surrounding the Imbrium Basin (R. E. Eggleton and T. W. Offield, 1970). As expected from the apparently allocthonous samples returned from the Apollo 11 and 12 sites, the highland rocks are much richer in plagioclase than the mare rocks sampled earlier. Most of the Apollo 14 samples are breccias with a wide variety of clast types and matrices. The local geology is dominated by Cone Crater, a bright-appearing, fresh, blocky crater with a diameter of 340 m located at the crest of a ridge. Spectacular blocks up to 5 m across occur on the rim of Cone Crater. Most of the well-indurated breccias appear to be part of the Cone Crater ejecta blanket. Some very friable breccias of relatively high albedo ("white rocks") were found only on the rim of the crater and are thus believed to have been derived from a deeper level than the breccias of more normal albedo. Other poorly lithified breccias scattered over the traverse area are probably shock indurated soil.

As many as four generations of breccia within breccia in some samples indicate that multiple shock events have affected these rocks. This history probably reflects successive development of circular basins and large craters with formation of the Imbrium Basin being the last of these major events.

Three major geologic features defined on premission maps (M. H. Carr and others, 1971) were visited during the Apollo 15 mission: (1) The mare surface of Palus Putredinis in an area that is crossed by a faint ray from either of the craters Aristillus or Autolycus, (2) Hadley Rille, and (3) the Apennine Front. It was expected that the mare material would be primarily basalt with some contribution of material from the ray that crosses the mare surface and that the front would be blanketed by ejecta, probably breccias, from the Imbrium Basin. It was also postulated that some material of the front might have been derived from bedrock beneath the blanketing material and excavated by cratering processes.

A large part of the mare surface on the landing site probably has been contaminated from other sources. In addition to the contribution of foreign materials from the ray, the Apennine massifs, being topographically higher, have also contributed material to the mare surface by crater ejecta transported off steep slopes. A simple fourfold classification of the returned rock samples that weigh more than 20 g shows a logical relationship of the sample types to the map units. The categories are (1) mare-type basalts, (2) non-mare-type basalts, (3) breccias containing mare-type basalt clasts, and (4) breccias that do not contain mare-type basalt clasts. The following table shows the distribution of these rock types.

Distribution of rock samples weighing more than 20 g

	Front	*Mare*
Mare-type basalts	0	21
Non-mare-type basalts	1	0
Breccias containing mare-type basalt clasts	7	7
Breccias that do not contain mare-type basalt clasts	17	4

Breccias with mare-type basalt clasts that were collected from the front were all on the down-range side of the south cluster of secondary craters, suggesting that the secondaries are a possible source of these breccias. The breccias without mare-type basalt clasts that were collected around the Lunar Module are likely to be part of the ray material; alternatively, some may be material ejected from craters on the Apennine Front.

The mare basalts were collected primarily from the rille rim, where the regolith is thin, and from the rims of Elbow and Dune Craters which are large enough to have penetrated through the regolith into the underlying mare basalts. Four of the basalt samples from the rille were collected from two large rocks that almost certainly represent local bedrock. The basalt samples from Elbow and Dune Craters have a high probability of being derived from local bedrock. The distribution of basalts that were collected from the rille edge and from Elbow and Dune Craters suggests that pyroxene-rich basalts are the dominant mare rock types to a depth of 80 or 90 m. At one station, however, it appears that an olivine-phyric basalt unit may overlie, at least locally, the pyroxene-rich basalts.

Hadley Rille is most likely a collapsed lava tube as interpreted by K. A. Howard and others (1972). Part of its

trend is controlled by premare structures, but elsewhere the course is more random. The rille cannot be a simple fault because the two sides do not fit together; instead, at bends, the outside has a greater radius than the inside, a geometry due partly to recession of the rim through mass wasting. The rille owes much of its present profile to collapse, as if into a buried conduit or deep narrow trough. Along its entire length, the deepest parts are the widest, a relationship different from that shown by river channels in which depth and width vary inversely so that the cross sectional area tends to remain constant. The rille geometry can be explained by collapse with more extensive foundering at the widest points. The possibility that the mare surface subsided approximately 100 m after it crusted over is suggested by an unevenness of the surface, a cap of marelike rocks on North Complex, a possible high-lava mark on the base of Mount Hadley, and grabens at the margin of the mare. Such a subsidence could have resulted from drainage into and along a lava tube that became the rille.

Well-developed systems of apparent lineaments, suggestive of fractures or compositional layers were observed by the Apollo 15 crew and recorded by surface and orbital photographs of Mount Hadley and Hadley Delta. They have been studied by E. W. Wolfe and N. G. Bailey (1972). The preferred orientations of the lineaments are northwest, north, and northeast. This so-called lunar grid has been observed under very restricted conditions of low sun illumination which suggests that some of the lineaments may be illusions created by low angle illumination of randomly irregular surfaces. Experiments with models of granular materials show that oblique illumination produces systematic sets of apparent lineaments that resemble some of those seen at the Hadley-Apennine site.

LUNAR AND PLANETARY GEOLOGIC MAPPING

Mariner 9

The Mariner 9 spacecraft was placed into a 12-hr orbit around Mars on November 13, 1971, after 3 yr of planning by the Mariner Mars 1971 TV Team, headed by Harold Masursky and including J. F. McCauley, D. J. Milton, M. H. Carr, D. E. Wilhelms, L. A. Soderblom, R. L. Batson, R. C. Wildey, D. W. Arthur, and W. E. Borgeson. During the first 45 days of the mission most of the planet's surface was not visible because of a vast atmospheric disturbance, now designated as the "Great Dust Storm" of 1971. Because of the obscuration, the preplanned mapping mission was delayed, and a surveillance mode of operation was designed to search for and take pictures of relatively clear areas. The first geologically significant observations were based on pictures taken of four dark spots in the Amazonis-Tharsis region. These were interpreted as enormous volcanic constructional features, detectable only because they are high enough to project through the dust clouds (Masursky and others, 1972). Each is far larger than any single volcanic feature on Earth, and they have large, well-developed summit calderas.

With subsequent clearing of the storm, the preplanned systematic mapping of the planet was begun on revolution 100. During early 1972 most of the surface of Mars was covered by *A*-camera pictures having a resolution comparable to telescopic photographs of the Moon. *B*-camera (narrow-angle, high resolution) pictures were taken within the area of each *A*-camera picture and of selected geologic features. Mariner 9 has shown that Mars is far more heterogenous geologically than previously suspected from the earlier flyby missions. The analyses to date indicate convincingly that the planet has a geological style of its own different than that of either the Earth or Moon and suggest that it represents a body more highly evolved from a primitive state than the Moon but less evolved than the Earth.

Systematic mapping of Mars

During 1971 plans to systematically map the geology of Mars were formalized with NASA. A cooperative program involving both USGS and university geologists is planned with USGS responsible for overall program management. Among USGS prime responsibilities are (1) the development of planetary geologic mapping techniques, (2) the establishment of mapping stylistics and conventions, (3) the approval of map formats, (4) the codification of Mars stratigraphic nomenclature and symbology, (5) the distribution of suitable imagery and base materials to all investigators, and (6) final review and approval of all manuscript materials.

In addition, a study was undertaken to test the feasibility and practicality of mapping the Martian surface from Mariner 6 and 7 flyby photographs. An interagency report with several prototype geologic maps at various scales was prepared and distributed to participants in the program and to other interested scientists (J. F. McCauley and others, 1972).

Lunar geologic mapping

During 1971 all the remaining 1:1,000,000-scale lunar geologic maps were completed. The 1:5,000,000-scale synoptic map of the nearside, which summarizes the results of the previous decade of work in lunar geologic mapping, was published (D. E. Wilhelms and J. F. McCauley, 1971).

Additional 1:5,000,000-scale mapping work on the polar regions, the limbs, and farside began. B. K. Lucchitta reports that the north polar region is strongly influenced by features associated with the Imbrium Basin and that a thick deposit of ejecta is present north of Mare Frigoris along with a fracture pattern that is radial to the center of Imbrium. Pre-Imbrian crater clusters are abundant and may be secondary craters from older basins such as Serenitates and Humboltianum. Four large young craters including Anaxagorus produce a dense and regionally anomalous pattern of small secondary craters on the nearside of the north polar region. D. E. Wilhelms (USGS) and Farouk El-Baz (Bellcomm, Inc.) have found a clear distinction

between terrain affected by multiring basin formation and terrain not affected on the eastern limb and farside. The unaffected terrain consists of multitudes of overlapping large craters, and the other terrain has fewer craters and is mantled and subdued by basin ejecta or covered by light plains material in basin related depressions. D. E. Stuart-Alexander has found that the center part of the farside is dominated by multiring basins. A very old basin about 900 km in diameter and centered at 40°S. and 160°W. has been identified along with several smaller basins also not previously identified. Several patches of hilly and furrowed materials like those of the Descartes region are also present suggesting that the farside, as well as the nearside, experienced premare volcanism. The west limb of the farside being studied by D. A. Scott, M. N. West, and J. F. McCauley is covered in large part by the Hevelius Formation, the freshest and best preserved of the lunar basin ejecta blankets. This unit is constricted in its east-west distribution but extends in two enormous plumes far to the north and south of Orientale. The blanket gives way laterally to extensive circumferential tracts of light plains material which may be partly related to basin formation. A major feature of the south polar region which is being mapped by K. A. Howard is the Schrödinger Basin which is surrounded by huge rimmed valleys, interpreted as secondary impact gouges. A significant additional result has been the recognition of mare material containing superposed secondary craters from Humboldt and which may represent some of the oldest mare material recognized so far on the moon.

Morphologic studies

Application of an elementary technique of dimensional analysis, testing for geometric similitude, suggests an impact genesis for most lunar craters. R. J. Pike (1972) has used five topographic parameters to test lunar and terrestrial craters for similitude: The variation of rim diameter with (1) interior depth, (2) exterior rim height, (3) exterior rim width, and (4) rim crest circularity; and the (5) variation of exterior rim height with crater depth. By all five criteria, fresh bowl-shaped lunar craters between 10 m and 20 km in diameter are geometrically similar to fresh terrestrial meteorite craters and to craters produced by chemical and nuclear explosions at shallow depths of burial. They are not similar to fresh terrestrial calderas, maars, or cinder cones. A separate but related study (Pike, 1971b) supports these results. Most lunar craters exceeding 20 km in diameter fulfill only the last three criteria of similitude. The two geometric differences between larger and smaller craters, however, do not preclude an impact genesis for the larger craters but rather mark a size-dependent threshold of change in crater shape. Both formational and postformational geologic models explain morphologic as well as geometric differences between the smaller (simple) and larger (complex) lunar meteorite craters (Pike, 1971a).

TERRESTRIAL ANALOG AND EXPERIMENTAL STUDIES

Explosion craters

During 1971, two highly instrumented explosion catering experiments (Middle Gust I and II) were completed at the U.S. Air Force Test Site in southeastern Colorado. High-speed blast and normal aerial stereophotography, geologic surface mapping, structural mapping of deep excavations cut in the craters, and shock metamorphic petrographic studies have been completed by D. J. Roddy. These two cratering experiments bring the total to 15 studied in detail to date.

All explosion experiments using 20-, 100-, and 500-ton TNT (trinitrotoluene) hemispheres and spheres lying on or slightly above alluvium and hard rock surfaces have produced craters with structural deformation and topographic shapes analogous to certain large, terrestrial impact craters. In addition to central uplifts, other similarities include (1) highly deformed rims, (2) rim foldbacks with inverted stratigraphy (3) thin crater breccia lenses, and (4) similar scaled distances to concentric zones of rim and crater floor folded or faulted zones. Explosions in alluvium have produced fused material; those in hard rock formed shatter cones. The remarkable similarities in the types of deformation observed strongly indicate that many terrestrial craters were formed by shock waves generated at or near the ground surface; that is, by cometary bodies that volatilized at the time of impact. Thus there appear to be two major types of impacting bodies; namely, high-density objects composed of iron or stone and low-density, cometary objects.

If the shape of a terrestrial or lunar crater (bowl-shaped, flat-floored, or centrally uplifted) does indicate the type of impacting body, it should be possible to determine the distribution of these bodies in earlier solar system time by selected crater counts on planetary surfaces that have an age range determined by radiometric techniques.

Steinheim Basin, Germany

Field studies by D. J. Roddy at the 14-m.y.-old Steinheim Basin in Germany were completed to provide comparative structural data with other central uplift impact craters, particularly the Flynn Creek crater in Tennessee. Steinheim is the prototype of cryptoexplosion structures and was previously reported to be about 2.5 km across and 80 m deep. Recent field studies show a figure of about 3.2 km is more accurate for the rim diameter. The original crater walls still exist in places and are locally overlain by a thin unit of brecciated limestone that was sheared from lower levels and moved up the crater walls. Breccia that was initially ejected from the crater was later washed back down the walls and now overlies the thin "sheared" breccia unit. An unusual silica-cemented breccia overlying the east rim may contain chemical

or mineralogical traces of the impacting body; this material is now being studied in the laboratory. The crater walls and inner rim are complexly deformed, and some limestone beds are locally folded back upon themselves as at Meteor Crater, Ariz.

Abundant shatter cone fragments, previously unreported, were found in the breccia that was initially ejected and later washed back into the crater. These shatter cones were formed in the rocks that make up the flanks of the central uplift; their present location indicates violent ejection from the central part of the crater. This interpretation is consistent with that by D. J. Milton of large blocks thrown from the central uplift of Gosses Bluff, Australia. Preliminary interpretation of the Steinheim data further indicates that the structure is nearly identical in all respects with the Flynn Creek crater and, like the Flynn Creek crater, is interpreted by Roddy to have formed by cometary impact.

Lonar Crater, India

D. J. Milton, under the auspices of the Smithsonian Institution, participated in a field study by members of the Geological Survey of India which has established the impact origin of Lonar Crater, Maharashtra, India. Lonar Crater, 1,800 m in diameter and 140 m from the rim to a shallow lake in the floor, is excavated in a series of basalt flows of the Deccan Plateau. An impact origin had been suggested on the basis of gross form, but no direct evidence had been found previously.

The rim shows Meteor Crater–type synclinal folding and an apron of unmixed, unshocked, throwout debris. Mixed, shocked and unshocked debris occurs above this in a discontinuous layer up to a meter thick. This deposit contains maskelynite basalt, more strongly shocked fragments of basalt in which some melting and flowage have occurred, and basalt which has been completely melted by shock. Also present are pumiceous fragments or flattened bombs and fragile drops of black glass. The evidence of shock and melting is the best indication of impact, without finding actual meteorite fragments. Lonar crater is the only known terrestrial impact crater in basalt, and the shocked material provides excellent counterparts to some of the returned lunar samples.

Landforms of the coastal desert of Peru

A geomorphic reconnaissance of the eolian erosional and depositional features of the coastal desert region of Peru was made in cooperation with Peruvian geologists in preparation for analysis of Mariner 9 photographs of Mars. J. F. McCauley, M. J. Grolier, E. C. Morris and G. E. Ericksen carried out the study. The area studied occupies a 10- to 20-mi-wide belt extending from the Sechura Desert in the north to Arequipa near the southern end of the country. Depositional features studied include transverse and longitudinal dunes many miles in length, some lying in the wind shadows of the coastal mountains, and a variety of barchans including the Pur Pur dune, which is about 1 km wide between its horns. The deflation features of the Paracas Peninsula and the Nasca region were also studied in detail. Scientific highlights include (1) the discovery in the Sechura Desert of earlier pluvial stream channels that are now elevated some 10 to 15 ft above the present floor of the desert–an example of relief inversion caused by deflation, (2) a variety of wind erosion features, including streamlined "whaleback" hills, and (3) at least eight varieties of surface albedo variation of inorganic origin. Moving sand sheets that temporarily brighten and obscure the dark lag gravels of local basins in the Paracas area are the most significant of these for Mars applications. The sand sheets result from midday crosswinds moving into the basins as they warm from insolation.

LUNAR SAMPLE INVESTIGATIONS

Petrology of lunar rocks

O. B. James and T. L. Wright (1972) have established a classification system based on composition for Apollo 11 and 12 basalts and gabbros. They distinguish three major groups of Apollo 12 basaltic rocks–olivine-pigeonite basalts and gabbros, ilmenite-bearing basalts and gabbros, and feldspathic basalts; and two major groups of Apollo 11 basalts–ophitic ilmenite basalts and intersertal ilmenite basalts. Compositional variations between samples within groups are generally dominated by MgO variations, whereas differences between groups are primarily inverse variations of TiO_2 and SiO_2 or Al_2O_3 and FeO. Results of fractionation calculations indicate that the MgO variation trends are explained principally by low-pressure fractionation of early-crystallized olivine ± pigeonite ± chrome spinel. The Al_2O_3 versus FeO trend in the basalts might possibly be explained by near-surface fractionation, but the TiO_2 versus SiO_2 trend is not explainable in this way. Investigations of the TiO_2 versus SiO_2 trend in terms of possible processes of high-pressure fractional melting or fractional crystallization indicate that the compositional variations cannot be the product of simple variations in depth or degree of fractionation. The data are consistent with the view that the mafic magmas formed by partial melting in the lunar interior and that near-surface fractionation, with the exception of removal or addition of olivine, has not been extensive.

E. C. T. Chao, J. A. Minkin, and J. B. Best (1972) developed a classification of the Apollo 14 breccias based on their fragment population, nature of matrix, grain size and porosity, metamorphic history, and bulk chemical composition. The Apollo 14 breccias are complex and are characterized by a wide range of clast types and textures. The principal fragment types in the breccias are (1) hornfels-noritic microbreccias, (2) micronorite hornfels, (3) devitrified glass, and (4) ophitic and other kinds of basalt. Dark vitrophyric fragments, fine-grained anorthositic rocks and anorthositic breccias, olivine-rich rocks, pyroxene-rich fragments, and breccias with inclu-

sions of earlier breccias are also present, but they are comparatively rare.

The Apollo 14 breccias can be classified chiefly into regolith microbreccias, Fra Mauro breccias, and spherule-rich microbreccias. Further subdivisions are based principally on interpretation of metamorphic history. Twenty-six Apollo 14 breccias have been so classified.

The complex fragment types contained in Apollo 14 breccias represent multiple episodes of heating and fragmentation. They are probably pre-Imbrian and were not produced by the impact effects of a single event. The variability of their fragment populations signifies that a multiple intimately mixed fragment source probably existed in the upper part of the Imbrium site before the Imbrian event took place.

A classification of Apollo 14 fragmental rocks by H. G. Wilshire and E. D. Jackson (1972) is based on the relative coherence of the breccias and the dominance of light or dark clasts. Four groups are established by application of these criteria. Most clasts larger than 0.1 mm are lithic, and of these, fine-grained thermally metamorphosed fragmental rocks are the dominant types. Compound clasts reveal pre-Imbrian periods of fragmentation and metamorphism. The distribution of rocks at the Apollo 14 site suggests that the Fra Mauro Formation, presumed ejecta from the Imbrium basin, is stratified; units of light clast-dominant glassy breccias occur at the top and units of dark clast-dominant annealed breccias occur lower in the section.

As determined from petrographic and active seismic data and from comparison with the nature and distribution of terrestrial impact ejecta from Ries Crater, the geologic implications of the Apollo 14 Fra Mauro breccias were summarized and interpreted by E. C. T. Chao (1972) as follows:

1. Probably all well-annealed hand-specimen-size Fra Mauro breccias are pre-Imbrian clasts.
2. The ejecta from the Imbrium Basin were probably deposited at the Fra Mauro site at a temperature below that needed for annealing because of the small amounts of glass in Fra Mauro breccias and their high porosity as predicted by their low compressive wave velocity of 299 m/sec. The well-annealed Fra Mauro breccia clasts have high velocity (5.65 km/sec) and low porosity.
3. It follows from 2 that the geochronologic clock of the Fra Mauro materials was not reset by the Imbrian event. The age of the Imbrian event occurs between the youngest age of the pre-Imbrian clasts in the Fra Mauro breccias and the age of the ilmenite basalt from Mare Tranquillitatis which has not been effected by the Imbrian event; that is, between 3.88 and 3.65 b.y.

R. L. Helz (1972) has completed a petrographic and electron microprobe study of rock 14068. This walnut-sized object is remarkable for (1) its extremely MgO-rich bulk composition (20.4 percent olivine in the norm) coupled with fairly high Na_2O, K_2O and P_2O_5 contents, and (2) the texture of its groundmass, which appears to have been completely molten at one time.

The groundmass consists of ≈25 percent skeletal olivine (Fo_{78-80}) and ≈40 percent feldspar (average plagioclase composition $Ab_{21}An_{72}Or_7$) plus pyroxene, plus iron spherules. There are olivine-rimmed vesicles in the groundmass. The long axis (if any) of the olivine tends to be parallel to the vesicle wall. The texture suggests these are true vesicles, formed by a gas phase while the groundmass was plastic. The temperature required to melt such an olivine-rich composition must be considerably above 1,200°C.

Rock 14068 does not resemble any known class of meteorites in composition, nor does it closely resemble other Apollo 14 lunar material. The origin of this bulk composition and a mechanism for melting it are both unknown at this time.

Edwin Roedder (USGS) and P. W. Weiblen (Univ. Minnesota) (1972b) reported the discovery of numerous areas and fragments (clasts) of glass of potassic granite composition in Apollo 14 breccia samples. These have crystallized in part to form potassium feldspar, but the remaining silicate glass between the crystals is still potassic granite in composition (by electron microprobe) with over 9 percent K_2O and 73 percent SiO_2. The compositions obtained are very similar to those they found for one of the two immiscible silicate melts they reported earlier. Hence, they believe these clasts represent fragments of material of granitic composition that separated as a result of liquid immiscibility and were concentrated somewhere at the surface of the moon relatively near to the source of the Apollo 14 materials.

Detailed electron microprobe studies have been conducted by Roedder and Weiblen (1972a) on a heretofore unreported pink spinel, intermediate in composition between $MgAl_2O_4$ ("spinel") and $FeAl_2O_4$ (hercynite) and with only minor amounts of chromium, found to be common in some Apollo 14 samples. This spinel probably originated in a cumulate rock consisting simply of olivine, anorthite plagioclase, and spinel, with no pyroxene or ilmenite. Such a rock is one possible candidate for the deep-seated mafic cumulate counterpart of the anorthositic crust that has been proposed for the moon.

Lunar anorthosite 15415 was found by O. B. James (1972) to consist almost entirely of anorthosite (homogeneous $An_{96.6}$), with accessory diopsidic augite and traces of hypersthene, ilmenite, and a silica mineral. The rock has had a complex metamorphic history—the texture reflects at least two episodes of shearing (followed by intense and partial recrystallization, respectively), one episode of cataclastic deformation, and one or more episodes of shattering and fragmentation.

D. B. Stewart, Malcolm Ross, B. A. Morgan, D. E. Appleman, J. S. Huebner and R. F. Commeau (1972) have also carried out a petrologic study of lunar anorthosite 15415. It is composed of 99 percent anorthite ($An_{96.5}Ab_{2.9}Or_{0.3}$) of highly ordered structural state. One percent of the rock is composed of pyroxenes of four types: (1) Calcic-augite containing unmixed spinel, ilmenite, orthopyroxene, and

pigeonite, (2) homogeneous hypersthene, (3) subcalcic augite containing (001) pigeonite exsolution lamellae and sometimes rims of host pigeonite crystallized on subcalcic augite core, and (4) pigeonite and ferropigeonite containing exsolved augite on (001). The type 3 and 4 pyroxenes prove the magmatic nature of this anorthosite despite the obscuring of its original texture by late-stage recrystallization of plagioclase and type 1 and 2 pyroxenes.

The crystallization history of this rock as it now appears is that it is formed by fractional crystallization and flotation in a calcium-rich gabbroic magma which had previously precipitated magnesium-rich olivine and (or) orthopyroxene. It is believed that the type 3 and 4 pyroxenes crystallized from an entrapped interstitial liquid perhaps after floating to the surface of the magma. The very characteristic zoning found in the type 3 and 4 pyroxenes could only occur in volcanic rocks; a metamorphic history is precluded for these crystals.

Edwin Roedder and P. W. Weiblen (1972c) received small portions of the samples returned from the moon by the unmanned Russian Luna-16 mission. This sample was obtained by NASA in an exchange with the USSR. Although generally similar to previous lunar samples, one striking difference was noted. Electron microprobe analysis of the late-stage, immiscible high silica melt inclusions in the Luna sample show a much higher sodium content. Also, there is a strong inverse relationship between the K_2O:Na_2O ratio in the bulk rock and its residual high-silica melt for Apollo 11 and 12 and Luna 16. This may be a consequence of the stage at which plagioclase crystallizes.

Motoaki Sato succeeded in obtaining stable and reproducible oxygen fugacity readings with lunar basalts using the solid electrolyte method. A difficulty arose from the fact that lunar basalts contain extremely small amounts of ferric iron (0.00 weight percent by chemical analysis), and even a minute loss of iron to the conducting noble metal in the cell results in a large rise in the oxygen fugacity values. With a new technique which alleviated the problem, Sato found the oxygen fugacity values of 12022, for example, are slightly above those of the iron wüstite buffer up to 1,200°C. The values are, significantly, very close to the oxygen fugacity values corresponding to the minimum vapor pressure of the melt, indicating that the lunar basalts probably underwent a substantial volatile depletion by vacuum pumping at one time or another. Whether the depletion occurred during the initial accretion or during the final extrusion is inconclusive with the present data.

X-Ray crystallographic investigations

D. E. Appleman has carried out a crystal-structure refinement on a lunar plagioclase feldspar single crystal of composition An_{84}. The crystal came from Apollo 12 igneous rock 12038. It is triclinic $P\bar{1}$; a=8.180(3) A, b=12.874(3) A, c=14.196(3) A, α=93.45(2)°, β=116.06(2)°, γ=90.63(2)°: approximate cell contents $8(Ca_{0.834}\ Na_{0.161}\ Mg_{0.021}\ Fe_{0.011}K_{0.004})\ (Al_{1.784}Si_{2.176}Fe_{0.016}Ti_{0.003})\ (O_8)$. Reflections with $h+k$ even (a-reflections) are strong and sharp; b-reflections ($h+k$ odd, l odd) are moderately strong and slightly diffuse; c-reflections ($h+k$ even, l odd) are extremely weak and very diffuse, making almost continuous streaks parallel to b^*; d-reflections ($h+k$ odd, l even) are not observable. Several "split b" or "e"-type satellite reflections are present. Refinement was carried out by Fourier and least-squares methods using 4164 measured X-ray diffraction maxima of types a and b; type c reflections are too weak to measure. The resulting structure is very similar even in detail, to that found by Fleet, Chandrasekhar, and Megaw in 1966 for a terrestrial bytownite of composition An_{80}. The general ordering scheme for Al/Si appears to be the same, and the Ca/Na distribution is consistent with that tentatively proposed for bytownite. The degree of order is apparently close to the maximum permitted by the composition and space group. The observed diffraction effects are consistent with the hypothesis that the crystal consists of a mosaic of small, anorthite-like domains with similar structures, but displaced by the translation $(a+b+c)/2$, thus causing the extreme diffuseness or absence of reflections with $h+k+l$ odd. Some degree of compositional segregation between domains is also indicated, perhaps incipient exsolution.

Lunar glasses and lunar fines

E. C. T. Chao, J. B. Best, and J. A. Minkin (1972) have determined the color, refractive indices, and chemical composition of more than 200 glass particles of impact origin from the Apollo 14 fines and breccias. As was found for Apollo 11 and 12, the Apollo 14 glasses fall into distinct chemical groups with characteristic colors and ranges of refractive index. These chemical groups are interpreted as representing specific parent rock types. They may be fused fines or breccias, fused uncontaminated or contaminated igneous rocks, or fused metamorphic rocks.

The examination of plots of refractive indices, chemical variations, and CIPW norms indicates that there are at least eight distinct chemical groups of Apollo 14 rock glasses of impact origin. (Thetomorphic plagioclase glass produced by shock is present in Apollo 14 samples but is not considered here). The most abundant group, with a compositional range overlapping that of the Apollo 14 fines and regolith microbreccias, is similar to hornfels-noritic microbreccias or micronorite hornfels in composition. Only one distinct group, with an anorthositic gabbro composition, is also present among Apollo 11 and 12 fines. The other parent rock types indicated by the study include rocks of anorthositic, feldspathic peridotitc, troctolitic, peridotite and mare basalt compositions. Glasses of salic composition are also present but are very rare.

A major conclusion from this study is that the dominant parent rock type of the Apollo 14 highland site is similar in composition to annealed noritic rocks rather than anorthosite.

The 70 to 1,000 μ size fractions of six regolith samples from the Apollo 14 site have been characterized in terms of their components by M. H. Carr and C. E. Meyer (1972). Fifty to eighty-two percent of the regolith fragments are glassy, either transparent homogeneous glass or dark cloudy glass. Seventeen to twenty-eight percent of the fragments are metabreccias of which two types are recognized; dark metabreccias, most common in samples close to Cone Crater rays, and light metabreccia fragments which greatly predominate elsewhere. Recognizable igneous rock comprises 0.0 to 6 percent of the regolith fragments; 4 to 14 percent are mineral grains. The locally derived fragments are compositionally similar to the relatively rare soil fragments at the Apollo 12 site that are rich in potassium, rare earth elements, and phosphorous (KREEP) and include most of the glasses and all the metabreccia fragments. Their relative proportions are consistent with derivation from a rock sequence in which light clast-dominant rocks are close to the surface and dark clast-dominant rocks are at greater depths. Included also is an exotic component from two main sources, the nearby mare and a unit with the composition of feldspathic basalt, possibly the Cayley Formation.

Age determination and isotopic studies

Mitsunobu Tatsumoto, C. E. Hedge, B. R. Doe, and D. M. Unruh (1972) investigated the U-Th-Pb and Rb-Sr systems on selected Apollo 14 samples. Concordia diagrams of U-Pb and U-Th-Pb on whole samples of breccias and basalt and those of density fractions of basalt were plotted. The data show that if the source material of these rocks is 4.65 b.y. old, it was modified by an event about 3.8 b.y. ago. This is in agreement with the Rb-Sr data.

Perhaps the most significant feature in Apollo 14 samples is that most whole-soil and whole-breccia samples (and basalt 14053) give evidence of significant increase of lead relative to uranium and thorium. This contrasts markedly with samples returned by the Apollo 11 and 12 sites which give evidence of lead loss or no change in lead content relative to uranium and thorium content.

In the 3.8 b.y. event, the value of U^{238}/Pb^{204} in basalt 14310 and breccia 14063 decreased, and the values of U^{238}/Pb^{204} in basalt 14053, breccias 14307 and 14318, and soils 14030, 14163, and 14259 increased relative to their hypothetical source materials.

There is evidence for another probable event that occurred between 2 to 3 b.y. ago when breccias 14307 and 14318 underwent further increase in U^{238}/Pb^{204} while soils 14003 and 14259 decreased in this ratio. Basalts 14310 and 14053 and soil 14163, however, showed no evidence of the effects of this probable event.

Another event at about 900 m.y., which has been attributed to the impact that formed the Copernicus Crater, was also found in soils and breccias from the Apollo 12 mission. The effect of the Cone Crater event is not evident among the Apollo 14 samples investigated.

The lead isotopic composition of volatilized lead from some lunar soils was investigated by B. R. Doe and Mitsunobu Tatsumoto (1972). The lead was studied at temperatures from 600° to 1,350°C, and that which boils off in the 1,000° to 1,350°C interval always gives a date of 4.5 b.y. It is believed this is indicative of a highly refractory component (one capable of enduring high temperatures) in the soil. The ratios of Pb^{208}/Pb^{206} in the material suggest that it came from a source that had a thorium-uranium ratio of 2 to 3. Only one mineral from the moon appears to have these thorium-uranium ratios—tranquillityite (a zirconium-titanium mineral). If this is the source of the lead, a primordial mineral may have been found—or at least one that has persevered in the soil for 4.5 b.y.

J. N. Rosholt (1972) is using neutron activation to check the existence of Th^{232m}, an isomeric component of Th^{232}. A long-lived isomer of Th^{232} was suggested from interpretation of anomalous Th^{232}/Th^{230} activity ratios in crystallized rocks returned from Apollo 11 and Apollo 12 lunar missions. It could not be demonstrated that Th^{230} is in radioactive equilibrium with U^{238} in the lunar crystalline rocks as measured by alpha spectrometry; the excess of radioactivity at the alpha-particle energy of Th^{230} (4.66±0.06 Mev peak) was attributed to the alpha decay of Th^{232m}. In attempts to find clues to the existence of Th^{232m} by investigating the differences in nuclear properties of an isomeric pair, thorium separated from a variety of terrestrial and lunar source rocks was subjected to intense neutron irradiation at USGS facilities. Previous to irradiation with a total of approximately 5×10^{18} neutrons, purified thorium had been electrodeposited on pure titanium or evaporated from TTA (thenoyltrifluoroacetone) on pure aluminum counting disks. The purpose of this investigation is to determine if the suspected isomer of Th^{232} (Th^{232m}) can be distinguished from Th^{232} by a difference in the reaction products produced from neutron irradiation of thorium. The Th^{232} (n,γ) Th^{233} $\beta^-_{\rightarrow}$ Pa^{233} $\beta^-_{\rightarrow}$ U^{233} reaction will produce a measurable quantity of alpha-particle-emitting U^{233} on the counting disk. In addition to the expected U^{233} produced, a relatively large and unexpected activity of a 5.3-Mev alpha emitter was also produced. Preliminary measurements indicate that a part of the 5.3-Mev alpha activity decays with a half-life of approximately 40 days. Activity at the 5.3-Mev alpha energy has been produced in all irradiated thorium that has been measured but in variable quantities from one type of thorium to the other. If indeed this unidentified alpha activity was produced as a reaction product from neutron irradiation of Th^{232m}, it will provide a very sensitive technique for estimating the abundance of Th^{232m}, even in very small proportion in lunar and terrestrial thorium.

Physical properties of lunar materials

The specific heats of lunar soil sample 14163 and breccia 14321 were determined between 90° and 350°K by B. S.

Hemingway and R. A. Robie (1972). Measurements were made at approximately 10°K intervals. It was found that the specific heat of both materials increases monotonically from 0.06 cal/g °K at 100°K to 0.20 cal/g °K at 340°K. The values determined are quite similar to those obtained for Apollo 11 and 12 soil samples.

A. N. Thorpe (USGS) and Samuel Sullivan (Howard Univ.), with C. C. Alexander, F. E. Senftle and E. J. Dwornik (1972) studied the basic magnetic properties of 11 glass spherules from the Apollo 14 lunar fines. As was found previously for 14 similar spherules from Apollo 11 and 12, the temperature dependent component of the magnetic susceptibility obeys the Curie law in the range from room temperature down to 77°K. At temperatures less than 77°K the susceptibility is less than that predicted by the Curie law but shows a Curie-Weiss relation with a Weiss temperature of 3° to 7°K in contrast to 2° to 3°K found for tektites and synthetic glasses of tektite composition. A proposed two-component model and a theoretical expression closely predict the variation of the susceptibility of the glass spherules with temperature. The model infers that the Weiss temperature is associated not only with the antiferromagnetic mineral inclusions within the glass but also with a distortion of the octahedral ligand field.

Compositional data

Major, minor, and trace element analyses were made on a total of 21 Apollo 14 samples by a team consisting of H. J. Rose, Jr., Frank Cuttitta, C. S. Annell, M. K. Carron, R. P. Christian, E. J. Dwornik, P. F. Greenland, and D. T. Ligon, Jr. (1972).

Evaluation of the data shows that:

1. The Apollo 14 highland samples display the same nonterrestrial characteristics as found for the Apollo 11 and 12 mare samples—a high refractory element content, a low volatile element content, and a reducing capacity in excess of that due to ferrous iron.
2. A meteoritic contribution is evident in the soils and breccias of Apollo 11, 12, and 14, as indicated by their high Fe and Ni content and their enrichment in Zn, Co, Ba, La, Y, and Zr compared to their associated basalts.
3. The samples returned from the three missions are not members of a simple differentiation sequence.
4. The composition of Apollo 14 basalts reflects the presence of a feldspathic component, while the high Fe and Mg contents of the Apollo 14 soils indicate a high proportion of ferromagnesium minerals.

REMOTE SENSING AND ADVANCED TECHNIQUES

EARTH RESOURCES OBSERVATION SYSTEMS (EROS) PROGRAM

The EROS program, administered by the USGS for the Department of the Interior, has continued to support investigations of the use of remote sensing in the development, management, and monitoring of earth resources. This research is conducted in the bureaus and offices of the department, and in State, regional, and educational institutions. Many of the investigations have relied on simulations of ERTS multispectral photography and involve continuing study as part of the ERTS experiment. Others have involved instrumentation not included in the satellite configuration.

The launch of the first ERTS ushered in a new era in data acquisition and management. The EROS program, through its Data Center, has primary responsibility for the distribution of these data and other remotely sensed data to departmental users and the public. This center commenced operation in temporary facilities in Sioux Falls, S. Dak., in October 1971. Thus far, USGS aerial photography, NASA aircraft program photography, and Gemini and Apollo photographs of the earth have been acquired and cataloged so that requests for reproductions can be filled. Imagery from ERTS-A has been handled from the time of launch in July 1972.

Alabama.—The Geological Survey of Alabama has prepared a report identifying user categories and users of EROS-acquired data in Alabama. It represents the current status of remote-sensing activities in Alabama and provides insight into the degree of awareness of government and industry in Alabama to the potentials and limitations of various remote-sensing techniques.

Arizona.—The Arizona Regional Ecological Test Site (ARETS) project was established by the EROS program to test the feasibility and the applicability of an operating multidisciplinary team to apply remote sensor data to a State's diverse environmental and resources problems in a timely and effective fashion. During the past year the local, State, and Federal agencies in Arizona for the first time had direct access to remote-sensor data collected over the State through the ARETS project. The USGS has produced orthophotoquads from the high-altitude photography covering the Phoenix metropolitan area; these orthophotoquads are being used by local, State, and Federal agencies in connection with geological mapping projects, water resources investigations, land use studies, and determination of the alinement of a proposed major aqueduct. Arizona agencies are using the statewide data to plan land use, to detect and analyze changes in land use, to study drainage, to update road locations, to plan possible locations for future roads to confirm land ownership boundaries, and to map legislative reapportionment. They are also mapping vegetative cover, evaluating changes in wildlife habitat, locating deer kills, and using the maps as a base for recording telemetry data from radio-collared big game animals.

The U.S. Bureaus of Indian Affairs and Land Management have used NASA high-altitude photography of southeastern Arizona in the development of a natural-resources information system, the demonstration of which has been completed by Boeing Computer Services, Inc., under an EROS-funded contract. Source materials were provided by both Bureaus, including among others, soil maps, forest-type maps, land ownership or leasee maps, interpretations of high-altitude aerial photography, and point data for the demonstration area in southeastern Arizona. The data were digitized using a polygon approach and were manipulated to show capability for updating the data base, analysis, synthesis, and retrieval information on a geographic grid system. The retrieved information is displayed graphically as well as in tabular form. The system has no scale constraints. A handbook on the operation of the system is being prepared.

Mississippi.—The EROS program, in a continuing effort to design and test EROS and ERTS potential capabilities to serve regional needs, has established an Experiment and Evaluation Office at the NASA Mississippi Test Facility. The primary functions of the office are: to assist users in the surrounding States in the establishment of demonstrations, projects, or experiments which employ remotely sensed data from satellites and aircraft as an aid in securing solutions for local resource and environmental problems; to evaluate the utility of these as experimental and operational data systems; to provide local users with assistance in obtaining and using remotely sensed data; to provide local users with training in the interpretation and use of aircraft and spacecraft data and derived information; and to participate with other Federal and local State programs in directing research toward the development of natural-resources information systems.

Montana.—Under an EROS-funded contract, Stanford Research Institute investigated the possibility of estimating precipitation over the Flathead drainage basin, Montana, using ESSA 7 and 9 photographs, for the Bureau of Reclamation

and the Bonneville Power Administration. (See P. A. Davis and others, 1971.) Data from fall and early winter 1968 and spring and early summer 1969 were studied in order to make estimations of probable 12-hr precipitation for each of eight cloud categories. Although the data sets were dependent, encouraging results were obtained for short-term application of the cloud categorization technique. An alternative approach using average brightness data from digital representations of satellite photographs did not correlate as well with observed precipitation.

Nevada.—The University of Nevada, in conjunction with their continuing research on the application of ERTS data to arid regions under an EROS contract, have evaluated thermal infrared data acquired over the Lake Tahoe—western Nevada area. Since no temperature or emittance data were obtained at the time of the overflight, interpretations were made while comparing the imagery with color and color infrared photography at larger scale. Preliminary observations suggest that evaluation of vegetation vigor over large areas, measured by its effectiveness in dissipating its radiation load, might be done more easily with daytime thermal infrared data than with color infrared data.

North Carolina.—Study of the use of remote sensing for ecological research on national seashores along the Atlantic Ocean has been undertaken by Paul Godfrey (Univ. Mass.) for the National Park Service. The primary study area consists of the Cape Lookout and Cape Hatteras National Seashores, N.C. An accurate vegetation map showing the total area of each community is being prepared from low-altitude black and white photography. It has been found, however, that for most purposes, especially mapping underwater vegetation, infrared photographs taken at 60,000 ft can be used readily, following enlargement. Infrared film is substantially better than other films for terrestrial vegetation mapping, and its use has made it possible to easily differentiate underwater vegetation, bare bottom, shoals, salt marshes, woodlands, thickets, grasslands, dune areas, and bare beach. Water depths in the sounds can also be roughly determined. For these reasons, infrared film is the most useful all-purpose film for seashore studies. The high resolution from high altitude also greatly simplifies general vegetation mapping and cuts costs because one frame covers more than 10 mi. Dramatic changes in underwater vegetation in and bordering the Cape Lookout National Seashore have been recognized on aerial photographs, and an attempt is now being made to correlate infrared imagery with standing crop and species composition for use in detecting future changes.

South Dakota.—A study of the use of remote sensing in making a soil and range inventory of Indian lands in South Dakota using aerial multispectral imagery is being made by the Remote Sensing Institute of South Dakota State University for the Bureau of Indian Affairs. Preliminary research has indicated that the optimum time for securing photographs or imagery to identify and map soil limitations occurs when the soil surface patterns are most apparent, in this area in May. Even at the optimum time only 59 percent of the soils could be so mapped. Density slicing analysis provided additional and more accurate information than did the existing soil map; the photographs used in density slicing analysis, however, must be of excellent quality and corrected for sun angle and vignetting effects to be most effective.

Tennessee.—The TVA has a contract with the Association of American Geographers, Commission on Geographic Applications of Remote Sensing, to study in depth the application of remote-sensing data in the TVA and in particular to formulate the information systems capable of providing the data base for monitoring environmental change. This study is a continuation of work for the EROS program by RCA. An annotated literature survey (N. R. Nunnally, 1971) has been completed, and the information needs and interests of TVA with respect to information to be supplied by very high altitude imagery and satellite imagery have been defined (J. B. Rehder, 1971). It has been suggested that photomorphic analysis has the ability to show the location of any discordant relationship between land use and landscape characteristics and that the methodology should provide an effective diagnostic tool in regional studies. In order to determine the utility of the photomorphic concept for landscape analysis to the TVA, a model was developed, and the proposed methodology and sampling techniques to be used in conjunction with a demonstration of this project were prepared (D. D. MacPhail and Yuk Lee, 1972). In addition, A. D. Hellman and Rex Petersen (Southwest Texas State Teachers College) have mapped lineations apparent on a small-scale photomosaic of very high altitude photography of part of the TVA and are preparing a report on the geologic and geomorphic significance of these.

Texas.—A remote-sensing survey of San Antonio Bay, Texas, by North American Rockwell Space Division (R. A. Nash, 1971) under an EROS-funded contract with the Bureau of Sports Fisheries and Wildlife, was conducted to learn whether the shell-dredging operations in San Antonio Bay constituted a hazard to wildlife at the Aransas National Wildlife Refuge. The quantity and dispersion of suspended sediments attributable to the dredging were investigated, and currents were studied by means of thermal infrared imagery and dye tests. These investigations resulted in an understanding of the current circulation pattern for ebb-flow conditions. There is a current divide in the strait between San Antonio Bay and Aransas Bay which prevents most of the dredging sediments from moving between the two bays except during occasional high tides.

Virginia.—The Bureau of Outdoor Recreation has contracted with the University of Virginia to examine the specific data needs for outdoor recreation planning and the ability of tested remote sensors to provide these data. The investigation, directed by W. E. Reed of the University of Virginia (Reed and others, 1972) has included defining data needs, remote sensor capabilities, and availability of imagery; analyzing the advantages and problems of incorporating remote sensing data sources into ongoing planning data collection programs; and evaluating the use of imagery to derive data for a range of

common planning analyses.

Washington.—Investigation of wetlands in the Columbia River basin of Washington, under the leadership of H. H. Ham (Bur. of Reclamation), has been completed. Multispectral imagery was obtained and processed by the University of Michigan in an effort to detect areas where plants have been stressed by rising ground-water levels and salt-content increases from irrigation. Results have been evaluated in a field study that indicated remote-sensing techniques do not as yet represent a practical alternative to presently used methods for the systematic and repetitive detection of wetlands on a major irrigation project. The difficulty in interpretation in environmentally complex areas, the inability to "penetrate" earth materials, the dependence of equipment on optimum weather and other operating conditions, and the cost are considered to be the principal adverse factors; they do not, however, preclude the use of this technique in other ground-water studies.

As part of an integrated program to evolve operational ERTS data uses in the Pacific Northwest, EROS is supporting investigations at the University of Washington under the leadership of A. L. Grey, Jr., in the use of ERTS-type data in urban and regional planning. Land-use interpretation and mapping of sample areas using a 200-m grid cell is in progress. A land-use map of San Juan Island at a scale of 1:50,000 has been completed. It was interpreted from RC-8 color infrared imagery and, when field checked, was found to have an overall accuracy of 87 percent. Interpretation and mapping are being repeated using 1:60,000-scale black-and-white aerial photographs taken in 1965 to allow for evaluation of comparable advantages of the two films at similar scales.

APPLICATIONS TO GEOLOGIC STUDIES

Quantitative discrimination of geologic units from satellites

The Nimbus satellites are a series of spacecraft carrying sensors designed primarily for repetitive meteorological observations. Their near-earth, sun-synchronous polar orbit provides viewing of a given point on the earth's surface twice every 24 hr, once in daylight and once in darkness. Nimbus data at 8-km resolution have been analyzed by H. A. Pohn, T. W. Offield, and Kenneth Watson in a new way to obtain maps of an important thermal property by which regional geologic units can be discriminated and inferences of rock type can be made. Digital data on daytime reflection primarily at 0.7 to 1.3 μm (Nimbus III High Resolution Infrared Radiometer) and day and night emission at 10.5 to 12.5 μm (Nimbus IV Temperature-Humidity Infrared Radiometer) were used in a study of the Oman area of the Arabian Peninsula. Photofacsimile film strips showing the data in analog form revealed little of geologic significance, and separate maps constructed from the digital data of reflectance and night ground temperatures were not a great deal more useful than the film strips. A map of day ground temperatures, however, showed a significant although rough correlation of temperature distribution and geologic units.

This correlation was considerably improved when a temperature-difference map was constructed by making an overlay from the day and night temperature maps using conspicuous features as tie points. The map demonstrated that such units as chert, eolian sand, wadi alluvium, limestone, and ultramafic rock each had a fairly distinctive temperature pattern, but it also showed distinctions which did not match the 1:2,000,000 reconnaissance geologic map originally used. By adding surficial units to the original geologic map from a desert environment map at larger scale and from a Gemini photograph, it was found that the temperature-difference map accurately distinguished areas of deflation (gravels) from areas of sedimentation (sands) and indicated the presence of unmapped wadis in the Oman Mountains region.

The next stage in the analysis was to derive a thermal property for the geologic materials which would be useful to discriminate units and provide some inferences as to their rock type. The diurnal surface temperature is controlled by rock properties such as thermal inertia, albedo, and emissivity and by parameters that control the insolation and radiance from the sky such as latitude, season, and ground elevation. The temperature-difference map provided a useful correlation with some of the geologic units because the difference enhanced the effects of thermal inertia and minimized those due to insolation, emissivity, and ground elevation. A computer-derived thermal model was then used to calculate thermal inertia values from the satellite temperature-difference and reflectance data. The resulting thermal-inertia map showed even more distinctive patterns for most of the geologic units. Some discrepancies with the geologic map remained, suggesting either mismapping or misidentification of units in an area presumably done mostly by photogeologic techniques. A more detailed geologic map for one problem area was found that showed better agreement with the thermal inertia map. Other discrepancies still remain; some are so sharply defined that they are thought to show huge unmapped blocks within a mafic-rock mass.

With the advent of Nimbus V, such mapping could be done at 709-m resolution, which should be sufficient to discriminate smaller exposed geologic units for rapid reconnaissance purposes in unmapped areas of the world. The system should also be suitable for mapping near-surface moisture distribution in soils and along fracture zones because of the influence of water on the thermal inertias of soils. Although ERTS-B will provide thermal data at 220-m resolution, the midmorning orbit time will limit the extraction of thermal inertia data and hence restrict the unit discrimination capability.

New technique for discriminating iron-rich and iron-poor rocks and soils

During the last 5 to 6 years, laboratory studies have shown

that electronic transitions in the ferric and ferrous ions cause optical absorption bands in the near-infrared as well as the visible reflectance spectra of iron-bearing minerals and rocks. With proper filtering these spectral features can be used (1) to enhance the image contrast between certain important rock types including many metallic ore deposits and their host rocks, and (2) to provide information on the relative proportions of the total iron and perhaps on the oxidation state of the iron.

Comparison of Ektachrome and Ektachrome-infrared photographs obtained by L. C. Rowan from 52,000 ft during NASA/ERS Mission 102 shows that the image contrast between granite gneiss and amphibolite in the Beartooth Mountains, Mont., is significantly higher in the Ektachrome-infrared photographs; conventional black-and-white photographs show low contrast. Analysis of visible and near-infrared spectra shows that the amphibolite spectra have intense absorption bands at about 0.70 μm and 1.0 μm; the gneiss spectra have very weak bands. These spectral differences result in large reflectance differences between 0.65 and 0.80 μm, a region in which Ektachrome-infrared film is responsive but Ektachrome and conventional black-and white-films are not.

International Imaging Systems (I^2S) multiband photographs of two metallic ore deposits, and their host rocks show much higher contrast in the near-infrared than in the visible bands due to differential optical absorption in the near-infrared. The Homestake Mine near Cooke City, Mont., is located in the central part of a zoned Tertiary breccia pipe. The central zone, consisting of dacite breccia with 25 percent biotite and hornblende phenocrysts and disseminated copper and gold, is very dark in the near-infrared band. The peripheral zone is about 70 percent limestone and 30 percent dacite with limonite, pyrite, hematite, and some disseminated copper and gold; this zone is bright in the near-infrared band. Image contrast between the two zones is 35 percent higher in the near-infrared than in the visible bands. This spectral contrast appears to be related directly to the higher proportion of iron in the central zone.

Chromite-bearing ultramafic bodies and adjacent gneiss on the Hellroaring Plateau (in the Beartooth Mountains) show higher image contrast in the near-infrared than in the visible. Reflectance spectra show that this contrast is due to the effects of iron absorption in the ultramafic; the ultramafic reflectance decreases in the near-infrared whereas the gneiss increases. The photographic technique described is directly applicable to mineral exploration and geologic mapping from proposed satellite systems.

Potential of thermal infrared for geothermal exploration

A brief but intensive examination of high altitude, high resolution infrared imagery obtained of The Geysers area, California, was performed by Kenneth Watson, T. W. Offield, and L. C. Rowan including field checking of anomalies, near-surface thermal gradient measurements at critical localities, and theoretical analysis of the effects of various geologic and topographic parameters using a computer thermal model. They have concluded that (1) only high heat-flow anomalies which are commonly altered or steaming ground (fluxes at least several hundred times the average terrestrial heat flow) are discriminable in rugged terrain for optimum instrumentation settings, (2) even when the settings are optimal, lower level geothermal anomalies may not be distinguishable from effects due to slope, percent outcrop, lack of vegetative cover, and so forth, and (3) thermal modeling techniques applied to calibrate repetitive images, which are digitally processed to reduce the effects of geologic and topographic "noise," hold the greatest promise for detection of lower level geothermal anomalies.

Mount Etna eruption recorded by satellite

After news of a new outbreak that began on April 5, 1971, from the northeast crater area of Mount Etna, J. D. Friedman, working with the Nimbus project office of Goddard Space-flight Center, Greenbelt, Md., obtained analog tape playbacks from the High Data Rate Recording System on board the Nimbus IV satellite; the tape playbacks were demodulated to separate out infrared radiometer and image dissector camera records for several orbits over Mount Etna, during the April 6 to 8 period. Oscillograph (Visicorder) traces of infrared radiometer (11.5-12.5 μ) scan lines over Mount Etna revealed a sizable spike indicating transmission of volcanic radiation through the atmosphere at 23:25 G.m.t., April 6. Earlier the same day (11:30 G.m.t.), the Nimbus IV Image Dissector Camera System recorded an eruption plume of high albedo about 20 km long, extending southeast from the summit area of Mount Etna, where concurrent ground conditions during the Nimbus overpasses as reported by the Istituto Internazionale di Vulcanologia in Cantania included 100-km/hr winds from the northwest carrying volcanic gases plus steam from snow and condensed atmospheric water as well as tephra from both volcanic and phreatic explosions. By noon (local time) April 6, 1,500,000 m^2 were covered by freshly extruded andesite lava which had an estimated maximum temperature of 1,030°C.

Infrared studies of volcanoes in the Cascade Range

Aerial infrared surveys and ground reconnaissance of anomalously warm ground and fumarolic vents at the volcanoes of the Cascade Range were continued by J. D. Friedman (1971) and D. G. Frank, working in cooperation with pilots of the U.S. Forest Service infrared fire-control aircraft based in the Pacific Northwest. Predawn infrared images obtained in 1971 confirm the continued, active thermal emission from previously recorded thermal areas on Mounts Baker, St. Helens, Rainier, and at several locations in Lassen Volcanic National Park. By comparison with preexisting images of Mount Rainier, the 1971 imagery also confirms the

continued existence of the configuration and general pattern of intensity of thermal anomalies recorded several times since 1964. A field investigation at Crater Lake National Park in July 1971 did not reveal the source of warm effluents from Wizard Island, recorded on Nov. 4, 1970, but radiometer traverses by boat confirm lake surface-temperature variations.

Photogeologic studies of patterned ground in Iceland

In addition to field and aerial photographic data previously summarized (U.S. Geol. Survey, 1971, p. A198) on the occurrence, photoidentification, and genesis of patterned ground in Iceland's central upland, J. D. Friedman and others (1971) conclude that the optimum spectral band for registration of polygonal networks on film is 5,100 to 6,800 A where the negative microrelief of furrow patterns is discernible at low sun angles. Where vegetation (moss and lichen) concentrations occur within the surficial polygon furrows, the optimum spectral band is 7,000 to 9,000 A. The polygon nets at Lodmundarvatn, Domadalshals, and Budarhals are interpreted as the frost-crack type (in contrast to proper ice-wedge polygons) which originated generally during the 17th and 18th centuries. Wedge-shape fillings from the tephra horizons correspond in age to this period and may however, be fossil ice wedges. The surface patterns of the polygons have persisted, and in many places the old polygons have been reactivated within the last decade during especially cold periods. The recent climate of Iceland, however, has not been severe enough for the development of widespread permafrost in mineral soils within the area of the surfaces examined; these polygon nets are thus not surficial manifestations of permafrost, but they do provide an insight into geomorphic processes which were active three centuries ago.

Geologic mapping aided by low-oblique stereoscopic color photographs

A feasibility test was made of the geologic application of 35 mm color low-oblique convergent stereoscopic photographs taken from light aircraft in mountainous terrain. The test, conducted by H. W. Smedes (USGS) in collaboration with W. B. Hall (Univ. Idaho), involved 11 test sites which sampled a wide variety of terrain conditions in Montana, Wyoming, and Idaho and was conducted to support actual mapping projects of 13 geologists.

This technique is simple and inexpensive, and the results were highly successful. They provided an important supplement to conventional vertical aerial photographs and afforded a link between those photographs and the view as seen from the ground. When used prior to fieldwork, they saved much field time; when used in conjunction with fieldwork, they resulted in greater mapping accuracy and made it possible to interpret some relations not otherwise determinable.

Several tests involved areas that had already been mapped in detail. In those areas, errors in mapping were quickly determined and corrected by use of the low-oblique color stereophotographs. Evaluation of these tests shows that the technique is applicable to a wide variety of disciplines in addition to geology, including forestry, ecology, range management, pedology, land-use inventory and management, and studies of the environmental impact of the activities of nature and man.

Photogeologic evaluation of ERTS-type imaging for surface geologic mapping

Photogeologic mapping of the eastern half of the Phoenix 2-degree quadrangle, Arizona, by T. N. V. Karlstrom includes the use of ERTS-type imaging systems as a test of their potential as a tool in rapid geologic mapping. Preliminary results, in part checked by field observations in critical sites, indicate a series of gravel terraces and gravel capped upland surfaces that record a detailed late Cenozoic record of changing fluvial conditions affecting past and present hydrologic and other critical environmental parameters in the Phoenix area. Numerous ancient habitation sites, fields, and irrigation systems are associated with the terraces and should provide datable materials for a refined chronologic reconstruction of the latest fluvial events that directly affected prehistoric migrations and cultural adaptations in the region.

In the Lake Pleasant area, high-level fluvial gravels rest unconformably on fine-grained, tilted, and deformed lake deposits with intercalated and intruded volcanics that appear comparable to Tertiary lake beds in Verde Valley to the north. Preliminary structural and stratigraphic observations thus suggest relatively late Tertiary tectonism that dramatically altered preexisting topography with (1) destruction of an extensive pluvial basin, and (2) initiation of the complex sequence of late Cenezoic aggradational and erosional events that first partially or completely buried, then progressively exhumed, the present tilted mountain blocks underlain by sedimentary, volcanic, and locally mineralized rocks ranging from early Precambrian to Cretaceous in age.

APPLICATIONS TO HYDROLOGIC STUDIES

Microwave emission from Arctic Sea ice

W. J. Campbell reported that measurements of microwave emission from Arctic Sea ice were made with aircraft at eight wavelengths ranging from 0.510 to 2.81 cm. Distributions of sea ice and open water were thus mapped from altitudes as much as 11 km in the presence of dense cloud cover. The expected contrast in emissivities between ice and water was observed at all eight wavelengths used. Furthermore, different forms of ice exhibited strong contrasts in emissivity. Emissivity differences as high as 0.2 were observed between two types of ice at 0.811-cm wavelength. The higher emissivity ice

type was tentatively identified as having been formed more recently than the lower emissivity ice type.

Remote sensing of water quality

M. C. Goldberg and E. R. Weiner studied the applications of remote sensing to determine water quality and concluded that, to obtain definitive information, use of a molecular spectroscopic technique is necessary. From a practical point of view, laser-Raman spectroscopy is one of the few methods of "one-sided" spectroscopy that gives the desired information. Investigation of detection sensitivity by this technique indicates that a lower limit of 10 mg/l can be obtained for the NO_3^- anion using "off-the-shelf" Raman configurations. Electronic techniques of reducing the signal-to-noise ratio may enhance the detection sensitivity by as much as three orders of magnitude. The ratio that determines the sensitivity of detection, however, is the solute signal to the water signal, both of which lie above the noise level. Thus the ultimate sensitivity increase may be more than three orders of magnitude. There is a real possibility that the detection level for each molecular species may be brought to 0.1 mg/l. This sensitivity is acceptable for monitoring water quality.

Thermal imagery of influent and effluent streams

E. J. Harvey, L. F. Emmett, and John Skelton of the USGS and J. H. Williams (Missouri Geol. Survey and Water Resources) in studying the hydrology of Green and Reynolds Counties, Mo., noted that many streams in the carbonate rock terrane of the Missouri Ozarks lose water to the subsurface bedrock and valley fill. Gaging stations record streamflows, and determinations of flow losses can be made, but it is not possible to gage all the valleys in this geologic province in which there is a loss in surface flow. Ground and airborne radiometric surveys made in all seasons and in various weather conditions suggested that surficial materials in a gaining stream valley are generally warmer in the winter months and cooler in the summer months than surficial materials in a losing stream valley. Although the diurnal variation in temperature of a losing stream valley may not be much different from that of a gaining stream valley, the annual variation of a losing valley is greater than that of a gaining valley. At the times of spring and autumn equinoxes the two kinds of valleys appear to have similar heating and cooling cycles. The largest differences in the cycles should occur during the winter and summer months. The possibility of distinguishing the characteristics of gaining and losing stream valleys is being investigated by the use of thermal infrared imagery in the hope that tonal contrasts will identify losing streams. Because all degrees of loss and gain exist in nature, the results of the investigation can only be qualitative.

Collection of hydrobiological information in Biscayne and Tampa Bays, Florida

A. L. Higer and A. E. Coker are engaged in environmental mapping of the Biscayne Bay and Tampa Bay areas to determine (1) the effects of the data scale, (2) spectral bands which provide the maximum hydrobiological information, (3) validity of remotely sensed data in detecting and identifying ecological changes, and (4) the applicability of techniques developed here to other geographical areas.

Hydrodynamic digital models of Tampa and Biscayne Bays have been completed and will serve as the base ground measurements for the collection of remote-sensor data from Skylab.

Detection of areas subject to fluoride and phosphate contamination, Alafia and Peace River basins, Florida

A. E. Coker reported that data were collected and processed to test the hypothesis that remote-sensing techniques can be used to detect areas subjected to fluoride and phosphate contamination by using the integrated effects of these contaminants on vegetation, terrain reflection, and temperature. The University of Michigan's scanner system was used to detect multispectral radiation consisting of various combinations of 18 spectral bands ranging from 0.32 to 14.0 μm over selected test sites. Multispectral recognition was performed using Michigan's SPARC (Spectral Analysis and Recognition Computer) to map water and evaporites containing high concentrations of fluorides and phosphates. In addition, sedgegrass, palmettos, and salt bushes were mapped for use as vegetal indicators of areas containing high-fluoride concentrations. Multispectral parameter mapping was performed using the SPARC to recognize spectral differences for vegetal indicators in relatively uncontaminated areas and in areas determined to have high concentrations of fluoride. Fluoride was treated as a parameter affecting the spectral signatures of the indicators, and estimates of fluoride concentrations were made by using the SPARC to recognize changes of the spectral signatures of the indicators. Preliminary analyses suggested that the processed data may be used to identify areas of fluoride and phosphate contamination.

Effects of geologic structure on ground-water flow in Alabama

According to W. J. Powell (USGS) and P. E. LaMoreaux (Alabama State Geol. Survey), movement of water along lineations observed in the Apollo 9 photographs has had an effect on the base flow of streams. Anomalies of streamflow, particularly during periods of low flow, have been known for some time. On October 13–14, 1971, a low-flow run was made along Talladega Creek, Talladega County, Ala. The pickup in flow from where the stream leaves the Piedmont to about 13 mi downstream was 64 cfs. The gain in flow for the main stream was 0.3 cfs per sq mi, which is not significant.

However, an analysis of the pickup in flow by subdrainage areas between the individual stream measuring sites indicated that there was a rapid pickup in streamflow at a point where two lineations intersect Talladega Creek. The pickup increased from 0.06 cfs per sq mi to 4.3 cfs per sq mi; at another segment of the stream where two lineations intersect the stream, the flow increased from 2.9 cfs per sq mi to 3.4 cfs per sq mi.

Turbidity plumes in Lake Ontario

Turbidity plumes in Lake Ontario, emanating from the Niagara River and the Genesee River, are clearly visible in high-altitude (60,000 ft) photography provided by NASA. E. J. Pluhowski reported that the Niagara turbidity plume is identifiable as far as 7 mi into the lake whereas the smaller Genesee River plume became indistinct in the photography within a half mile of the shoreline. By way of contrast, color and color-infrared photography obtained July 6, 1970, October 19, 1970, and May 30, 1971, of the south shore of Lake Ontario shows that the Oswego River turbidity plume is far less intense and is relatively poorly defined. From this it may be inferred that, at flight time, the sediment load of the Oswego River was much lower than that carried by either the Niagara River or the Genesee River.

Wetlands and sediment detection in the Long Island Sound area

Data obtained from two recent aircraft missions are being studied by F. H. Ruggles to describe wetlands and to delineate the movement of sediment. The earlier flight, in February 1970, photographed the shoreline of Connecticut from an altitude of 15,000 ft; the later flight, in October 1971, also covered the shoreline of Connecticut and included the north shore of Long Island from an altitude of 24,000 ft. All information and interpretation will eventually be correlated to the ERTS-A data.

The best plume and sediment delineations were obtained using ektachrome film with a W-8 filter. Encouraging results were obtained using color ektachrome film with a 2A filter, color-infrared film and a 15 filter, and black-and-white film with a 25A filter. Poor results were obtained with black-and-white film and a 47B filter. A preliminary review of the photographs indicated that sediment plumes from the Thames and Connecticut Rivers are affected by the volume of fresh-water inflow as well as hydrographic, hydraulic, and meteorologic conditions.

APPLICATIONS TO CARTOGRAPHIC STUDIES

During fiscal year 1972, the following identified research tasks were jointly supported by funds from the NASA and EROS program of the Department of the Interior. Actual research was accomplished by the Topographic Division.

Calibration of the Return Beam Vidicon (RBV) system

The EROS program is cooperating with NASA and RCA in a geometric calibration of the RBV system for ERTS, which is essential for register and cartographic referencing of high-resolution photoimage data. Final geometric register with an accuracy of 10 μm is sought, and the several functional parameters of geometric register require calibration to higher accuracy. The reseau, the focal length, principal point, radial distortion of the lens, and the electronic distortions of TV scanning and reproduction are the major elements of geometric calibration. Preliminary results indicate that the RBV system has stable systematic distortions that can be calibrated.

The USGS has also been conducting basic research on the distortion pattern in TV systems. Because of the availability of RBV calibration data and laboratory images provided by RCA, considerable attention has been directed to this system. The University of Illinois has been sponsored in a 3-yr research program. The final report for phase 1 describes in some detail the results of the first 9 months (K. W. Wong and others, 1971). Some in-house distortion studies have been conducted, and the pattern and magnitude of the errors have been plotted. These studies indicate that the RBV system may have an appreciable amount of distortion, which should, however, be very stable and amenable to calibration and subsequent removal.

Orthophotoquads from high-altitude (U-2) photographs

On November 5, 1970, a USAF U-2 aircraft, equipped with a calibrated mapping camera of 154 mm (6 in.) focal length, photographed the area covered by the Phoenix 1:250,000-scale map sheet (NI 12-7). The plane flew at 21.3 km (70,000 ft) above sea level, and the photographs were of excellent quality. The original film was made available to the USGS, and it was used to produce several significant experimental orthophoto products.

A 1:24,000-scale orthophotoquad of the Mesa, Ariz., 7½-minute quadrangle was produced by simple rectification. This photoimage product was printed on the back of the corresponding conventional line map to illustrate two approaches to mapping and their complementary aspects. The production of the orthophotoquad involved image magnification of × 5.75, which resulted in a somewhat fuzzy image when reproduced by both diazo and lithographic processes. The orthophotomap has horizontal positional accuracy at least equal to that of the line map of the same scale.

A 1:50,000-scale orthophotoquad of the Mesa 15-minute quadrangle was also produced and combined differential rectification (by Orthophotoscope) with conventional rectification. Since the magnification in this case was only × 2.87, the final product is of high image quality and has at least the

same level of information as the 1:24,000-scale orthophotoquad. The positional accuracy (ground reference) is practically the same as that of the 1:24,000-scale product, which means that it significantly exceeds NMAS for horizontal position. The product was first reproduced in diazo form but is now being reproduced in lithographic form on the back of the equivalent line map, which was made by combining four 1:24,000-scale line maps and reducing to 1:50,000 scale.

A 1:250,000-scale (1° by 2°) orthophotoquad was also produced of the Phoenix (NI 12-7) area. Preparing this product again involved the combination of Orthophotoscope scanning and conventional rectification. Image quality is excellent and limited only by the reproduction process. Positional accuracy meets the requirements of the NMAS. Original prints were made with the diazo process, but lithographic reproduction is also being accomplished.

All three of the above products were prepared for reproduction in random-dot form so that the use of rectilinear screens is not required. This relatively new image-processing technique shows promise of significantly improving the resolution (image quality) of photoproducts that are reproduced by diazo or lithographic methods.

Data bank of space-photo control

Photographic control points in the 50 States, Guam, and American Samoa have been selected for a data bank for use in locating and positioning imagery from orbiting spacecraft and high-flying aircraft. Each point in a State has a unique number, geodetic coordinates, elevation, and descriptors, which are recorded on a standard ADP 80-column punched card. In addition, each point is circled on a 1:250,000-scale map, military (gridded) edition. The control is retrievable by area, State, or 1° by 2° map blocks.

A computer program has been prepared to read the data-bank cards, convert the coordinates to UTM if required, and generate commands to plot the points on transparent paper at 1:250,000 scale in map format. These transparencies are being used to check blunders by overlapping them on the annotated 1:250,000-scale maps. The transparent overlays are also used as reference library material that can be easily reproduced for distribution to users who wish to mark the points on a 1:250,000-scale map.

The completed data bank has been forwarded to NASA-Goddard to be used in the design of the precision processor of ERTS imagery.

High-altitude aerial photographic coverage of the United States

The Committee on Space Programs for Earth Observations, National Science Foundation, has recommended that the Department of the Interior, in collaboration with other agencies of the Government, prepare a program for systematically photographing the entire country from altitudes of 65,000 to 70,000 ft with cameras of cartographic quality. The photographs will not take the place of data to be acquired from satellites but will serve many related needs. One of the expected uses is to insure effective use of ERTS imagery by providing a cartographic base on which the data from the satellite can be plotted. Another proposed application of the high-altitude photographs is to establish horizontal control for larger scale mapping by aerotriangulation.

Remote sensing modes, platforms, and sensors

As a continuing research requirement, earth-sensing systems applicable to the EROS program are being defined and evaluated with respect to cartographic applications. Evaluations of sensing systems for ERTS and Skylab resulted in formal experiment proposals to NASA. Post-Skylab earth-sensing missions including those of the Space Shuttle were also examined and evaluated.

A formal study to compare the basic modes of imaging the earth, endorsed by advisory committees of the National Academy of Science, was proposed and is expected to begin this year as a project of the EROS program. Figure 5 below illustrates the basic modes and indicates their relative altitudes and performances.

Figure 6 summarizes the resolutions that might be expected from various earth-sensing systems.

In a project related to the EROS program, USGS authors compiled chapter 8 of the forthcoming "Manual of Remote Sensing", which is being sponsored by the American Society of Photogrammetry. The chapter, entitled "Platforms," describes balloons, aircraft, and spacecraft employed for remote sensing. A preliminary version was reproduced and distributed for comment during January 1972.

Gridding of 1:250,000-scale maps

During the past several years, many agencies and individuals who wish to digitize map data for computer processing have indicated a need for gridded maps. The EROS program has sponsored map gridding and has identified the UTM as the preferred grid.

An experimental 1:250,000-scale gridded line map (Phoenix) was prepared during 1970 and distributed for comment. As a result of the comments received and of related studies, application of the UTM grid to the 1:250,000-scale series was authorized. Initial printing of standard sheets with this grid is scheduled for the summer of 1972.

EROS Mapping Requirements Working Group recommendations

The EROS Mapping Requirements Working Group, chaired by the Cartography Coordinator of the EROS program, is an advisory body comprising formal members of eight bureaus of the Interior Department and monitoring representatives of the Departments of Agriculture, Commerce, Defense, and Trans-

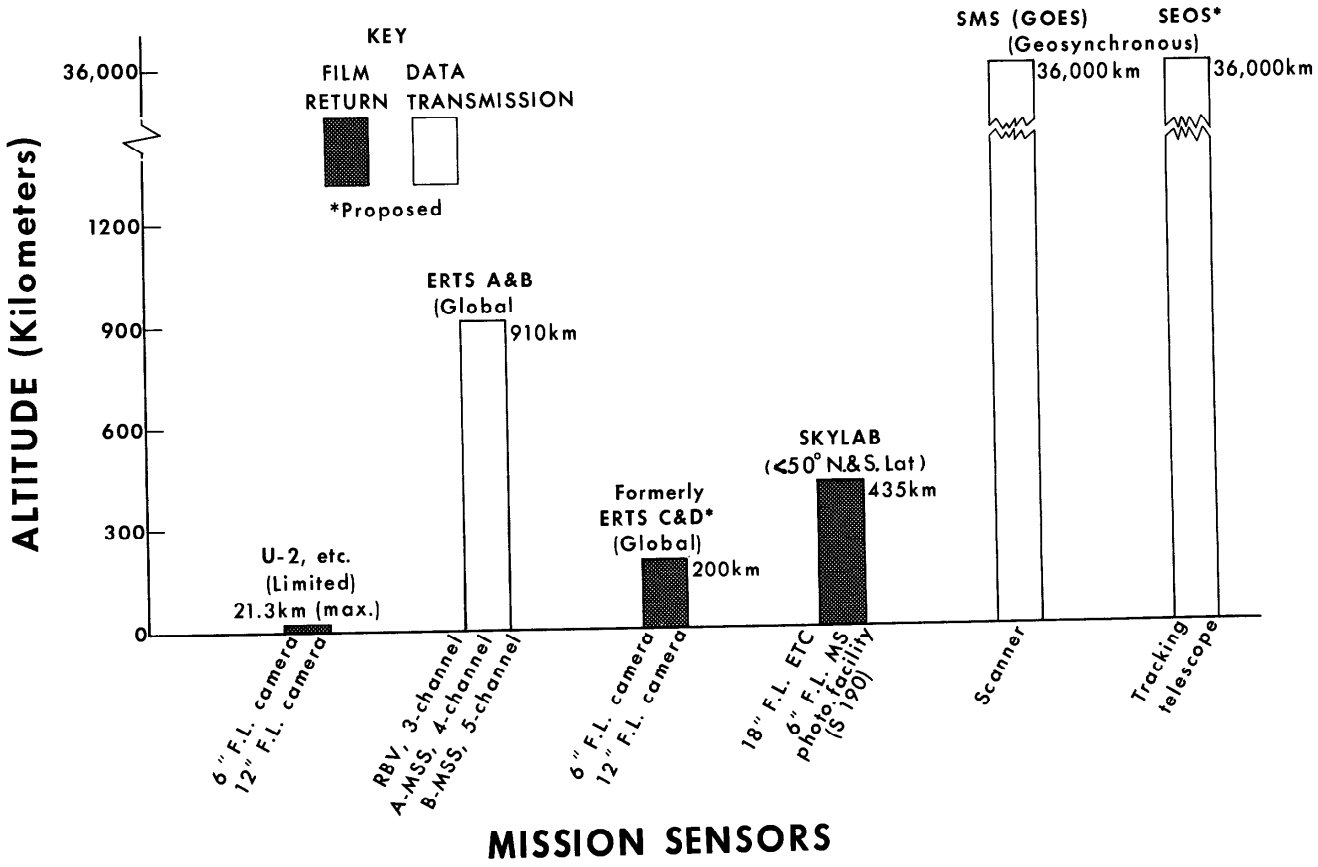


Figure 5.—Earth-sensing modes.

portation. In the period of this report, the group has accomplished two significant research-related tasks. The first was the development of a plan and specifications for covering the United States with high-altitude (above 60,000 ft) photographs.

The second task was a study of EROS mapping needs, which led to the preparation of the document "Recommendations on Map Specifications." This document was unanimously endorsed by the members representing the Interior bureaus. The highlights are summarized below:

Accuracy: When feasible, maps should meet NMAS and should be so certified. Maps of known accuracy not meeting NMAS should carry an appropriate accuracy statement.

Projection and grid: The UTM is the preferred projection for new map series (except in polar regions where polar stereographic is recommended). The maps should carry geographic reference marks and a fine-line UTM grid.

Type or form: Line maps (symbolized) are the basic cartographic products. Photoimage maps are recognized as useful substitutes for line maps where no map coverage exists and as complements where line maps do exist.

Scales: As new map series are introduced, they should be published at scales compatible with the metric system.

Vertical reference: Maps that are metric in the planimetric sense and "English" in the vertical sense are acceptable until the metric system is adopted nationally.

Format: New map series at scales of 1:25,000 or larger should be formatted to grid lines. At smaller scales the format should be defined by latitude and longitude.

Data Center for EROS program

The EROS Data Center is being established near Sioux Falls, S. Dak., as a key installation in the handling of data obtained from aircraft and spacecraft for earth resources studies. Under the management of the USGS, the center will be a repository where data will be received, processed, and filed for use by scientists throughout the world. The facilities of the center will be available to provide professional and instrumental assistance to users of the data.

The first major source of data will be NASA's ERTS-A and B. ERTS-A was launched in July 1972. The satellites carrying photographic and remote-sensing equipment will eventually return each year about 50,000 images (RBV photographs) of a wide variety of land and water features of the United States. Repetitive images of such features will be used to improve

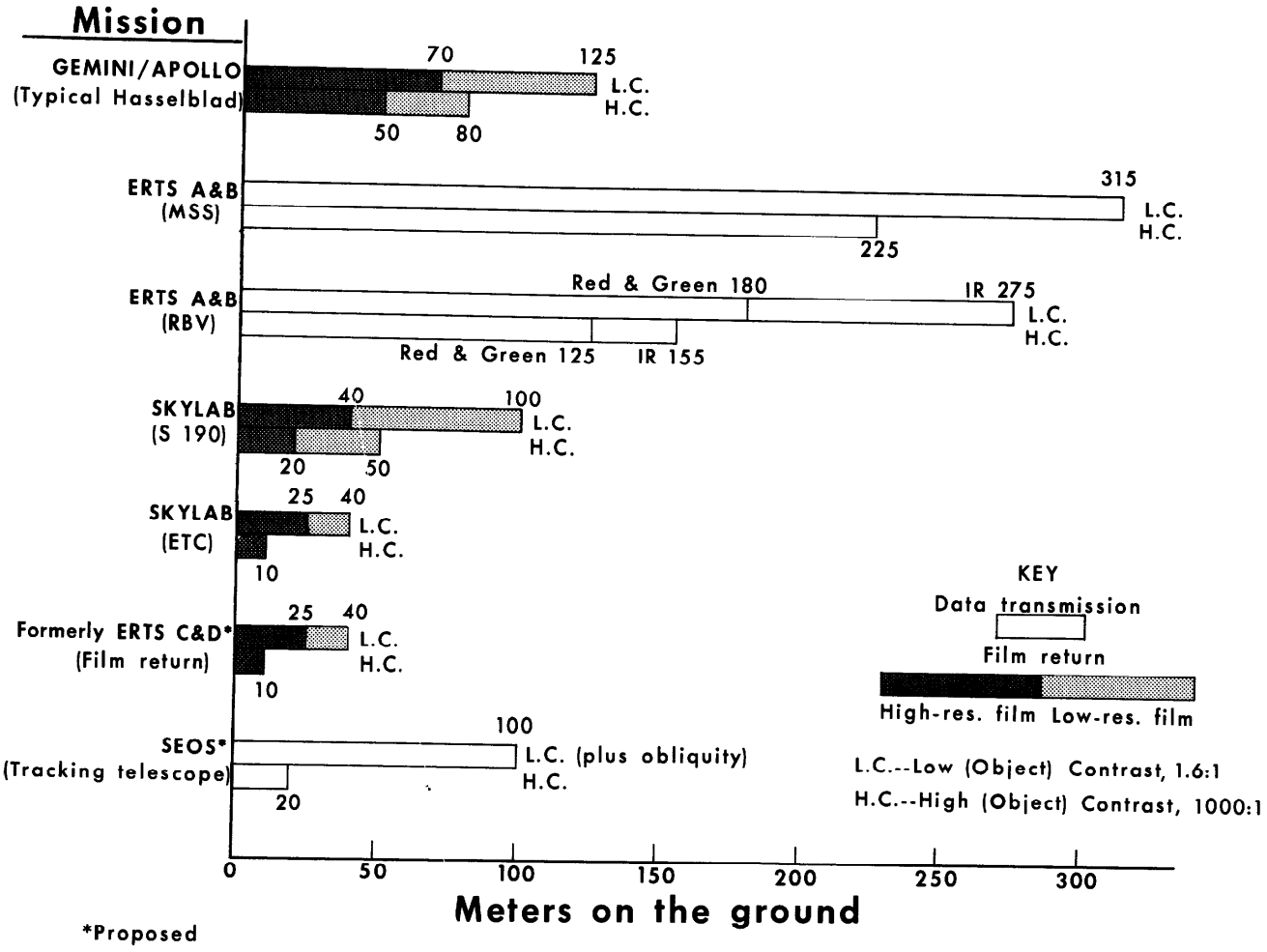


Figure 6.—Earth-sensing resolution estimates (based on photographic criterion—resolution of bar target pairs).

knowledge of our natural resources.

The center will also handle NASA aircraft imagery, USGS high-altitude aerial photographs, and computer compatible tapes of ERTS and NASA aircraft data.

Autographic Theme Extraction (ATE) system

This task involves the binary (yes or no) representation of a subject or theme that has been isolated from an image and yet retains the precise geometry and resolution of the original image. An extractable theme must have a unique, strong, and reliable spectral signature with respect to its surroundings so that semiautomated processes rather than human interpretation can be used to isolate the theme on the basis of hue and density differences.

Density correction to normalize each photographic image is the first major step in ATE. In this step, each image to be used in theme extraction is sampled for nonuniform scene illumination by measuring density on known similar image features such as open water. These density samples are then sent to the computer in digital form where a correction function is computed for the complete image. This function is called a correction surface and is defined by a series of mathematical terms. This correction function is then converted to analog form by constructing a density filter which corresponds to the computer correction function. When placed over the original image, this filter normalizes the density as though the scene were uniformly illuminated.

The second major processing function involves multichannel image analysis. The associated hardware permits spectrally variant images of a single scene to be scanned and stored in geometric register on a video disk recorder. Any combination of these stored images can be electronically processed for display on a television monitor. A trained operator can then determine and document the spectral band combinations and photographic processing parameters required to best isolate the theme from the original image.

The final major function is theme extraction by photo-

mechanical processing of images according to instructions provided in the density corrections and image analysis steps. As an alternative, digital processing could be used for isolating and printing the thematic extractions, but the photographic process as of today is considered to be more efficient and superior for retaining the resolution and geometry of the original image. To meet cartographic requirements in the final product, the geometry of the input must be defined and retained.

The ATE system is scheduled for installation at the EROS Data Center at Sioux Falls, S. Dak. by early 1973. The RBV cameras and Multispectral Scanner of the ERTS will provide the basic inputs to the system. The process, however, is also applicable to aircraft and spacecraft photographic products. The initial experimental effort will concentrate on mapping the following basic themes: (1) Open water, (2) snow and ice, (3) infrared-reflective vegetation, and (4) massed works of man.

The format of the thematic extractions may be that of the image frame or of a standard quadrangle map. In any case, precise earth referencing will be included which, in addition to latitude and longitude indicators, normally involves the UTM plane coordinate grid.

Color-balancing printer

To provide the means of correcting color anomalies as well as intensity balance in color aerial photographs, the USGS contracted with Ingenuics, Inc., to modify an available black-and-white LogEtronic printer. A successful model was made, evaluated, and accepted.

In principle, light from a single CRT with a mix of red, green, and blue phosphors is transmitted through three sequential sharp-cutting red, green, and blue filters during the exposure of original color photographs. A random electron beam scans the exposure plane, is transmitted by a collecting lens system through the respective filter, and is picked up by a photomultiplier, which controls the incremental exposure of a very small area.

Tests have shown that color anomalies greater than 0.10 density unit in any color are corrected and good color reproductions from off-color camera originals are produced.

ERTS-A and Skylab experiment proposals

Proposals have been presented to NASA with requests for funds to cover cartographic experiments with imagery from the first ERTS-A mission launched in July 1972 and the Skylab mission to be launched later. Skylab will be a manned mission and will return hard copy as opposed to the RBV imagery that will be beamed back to earth by the ERTS satellite. The investigations will include the use of ERTS imagery to compile photomaps at scales of 1:250,000 and smaller for partial revision of the 1:250,000-scale series. Investigations of the Skylab imagery will include photomapping at scales of 1:50,000 and smaller and partial map revision at various scales.

The following ERTS-A proposals have been accepted or are being negotiated:

Overall evaluation of ERTS imagery for cartographic application.

Investigation of ERTS/RBV and MSS imagery for photomapping of the United States.

Investigation of ERTS/RBV and MSS imagery for photomapping of foreign areas.

Experiments in cultural interpretation and map revision from ERTS-A data.

Investigation of ERTS-A imagery for application to thematic mapping.

Cartographic application of ERTS/RBV imagery in polar regions.

Cartographic evaluation of ERTS orbit and attitude data.

Cartographic evaluation of ERTS-A MSS imagery.

The following proposals have been accepted or are being negotiated relative to cartographic applications of data from the Earth Resources Experiment Package (EREP) and the Earth Terrain Camera (ETC) to be carried on the Skylab (estimated launch date May 1973):

Cartographic evaluation of Skylab-A S-192 scanner images.

Overall evaluation of Skylab (EREP) imagery for cartographic application.

Investigation of Skylab imagery for photomapping of the United States.

Investigation of Skylab imagery for photomapping of foreign areas.

An experiment in cultural interpretation and map revision from Skylab-A data.

Investigation of Skylab imagery for application to thematic mapping.

APPLICATIONS TO GEOGRAPHIC STUDIES

Land-use information and classification system

In February 1971 an Interagency Steering Committee was set up by a USGS-NASA working group with A. C. Gerlach (deceased) as Chairman. The Committee[1] has developed a land-use classification scheme for use with remote-sensing data from high-altitude aircraft and satellites. The first two digits of the classification are intended for rapid, easily updated national and regional overviews of current land uses and land use changes and trends. Third and higher digits could be

[1] J. R. Anderson (Chm.), Univ. Florida; W. A. Fischer, R. H. Alexander, and J. L. Place, USGS; A. B. Park, NASA; W. M. Johnson and J. A. Gockowski, SCS; E. E. Hardy, Cornell Univ.; R. A. Shelton, Univ. Illinois; R. F. Tomlinson, Internat. Geog. Union Comm. Geog. Data Sensing and Processing.

adapted to data from traditional sources such as low-altitude photography, field surveys, census records, and so forth.

At the end of June 1971 a Conference on Land-Use Information and Classification was held in Washington, D.C., and attended by approximately 200 officially designated representatives from Federal, regional, State, and local agencies. During the Conference, at both plenary and seven specialized sessions, several currently used land-use schemes were considered and discussed in detail. Agreement was reached in principle on the further development by the Committee of the land-use classification scheme originally prepared by J. R. Anderson (Univ. Florida) for the Association of American Geographers. A list of attendees, a set of the invited papers given at the opening plenary session of the Conference, and a set of the session reports have been mailed to participants.

Subsequently, a Subcommittee, consisting of J. R. Anderson (Chairman) and E. E. Hardy (Cornell Univ.), was set up by the Steering Committee to develop the land-use categories and their definitions in further detail. These land-use categories and definitions will also be reviewed by other Steering Committee members and selected Federal user agencies and will be tested in different regional situations.

The two levels of the classification thus far developed are as follows:

Level I	*Level II*
01. Urban and Built-up Land.	
	01. Residential.
	02. Commercial and services.
	03. Industrial.
	04. Extractive.
	05. Transportation, Communications, and Utilities.
	06. Institutional.
	07. Strip and Clustered Settlement.
	08. Mixed.
	09. Open and Other.
02. Agricultural Land.	
	01. Cropland and Pasture.
	02. Orchards, Groves, Bush Fruits, Vineyards, and Horticultural Areas.
	03. Feeding Operations.
	04. Other.
03. Rangeland.	
	01. Grass.
	02. Savannas (Palmetto Prairies).
	03. Chaparral.
	04. Desert Shrub.
04. Forest Land.	
	01. Deciduous.
	02. Evergreen (Coniferous and Other).
	03. Mixed.
05. Water.	
	01. Streams and Waterways.
	02. Lakes.
	03. Reservoirs.
	04. Bays and Estuaries.
	05. Other.
06. Nonforested Wetland.	
	01. Vegetated.
	02. Bare.
07. Barren Land.	
	01. Salt Flats.
	02. Beaches.
	03. Sand Other Than Beaches.
	04. Bare Exposed Rock.
	05. Other.
08. Tundra.	
	01. Tundra.
09. Permanent Snow and Icefields.	
	01. Permanent Snow and Icefields.

Census Cities project

The Census Cities project of the USGS Geographic Applications program is an experiment in urban-change detection using remote sensors aboard high-altitude aircraft and earth-orbiting satellites. Multispectral photography acquired for a rank-size sample of U.S. urban areas at the time of the 1970 census is being used as a data base for standardized measurement and comparison of land use in urbanized areas. Similar photography requested in 1972 will provide a basis for anaylzing gross changes in land use and for assessing the utility of satellite imagery for this purpose. J. R. Wray is the principal investigator.

This experiment is part of the Department of the Interior's EROS program and NASA's Earth Observations program. The project continues as one of the experiments which will use televised imagery from the unmanned ERTS.

During 1971, work was underway at eight of the urban test sites. Analysis of Boston and New Haven is being carried out under contract with Dartmouth College, Department of Geography, R. B. Simpson, principal investigator; of Pontiac, Mich., by the Oakland County Planning Commission; of Cedar Rapids, Iowa, under contract with the University of Iowa, Institute of Urban and Regional Research; and of Washington, D.C., by staff of the USGS Geographic Applications program. Under a contract with the Metropolitan Washington Council of Governments, the potential role of remote sensors in fulfilling the operational needs of metropolitan regional planners is being investigated.

Analysis of San Francisco, by far the largest of the urban test sites, is being carried out by USGS personnel at Menlo Park and San Jose State College, assisted by a team of USGS geographer-cartographers at Silver Spring, Md. Census Cities project work at Tucson and Phoenix is in the planning stage.

The USGS has prepared controlled and gridded photomosaics for all these test sites. The amount of urban land use actually classified in 1971 is about 11,000 sq mi, an area roughly equivalent in size to the State of Maryland. The mosaics, land-use information, and corresponding census statistical areas for these test sites will ultimately be combined as elements comprising the looseleaf "Atlas of Urban and Regional Change." This atlas is a prototype, user oriented, intermediate product and is designed as part of the Census Cities experiment. In 1971, prototype atlas sheets were prepared for Washington and San Francisco. Experimental computerized 1970 land-use maps were also made for Boston and Cedar Rapids. Changes believed to be detectable from satellite data were simulated for Boston and Phoenix. The land-use inventory and change-detection work, using remote sensor data, are being related to USGS urban pilot studies at the same test sites, particularly at San Francisco in 1971. Progress was also made in identifying a growing list of uses and users for these data.

Central Atlantic Regional Ecological Test Site (CARETS)

A jointly sponsored USGS-NASA demonstration project is underway in the Central Atlantic Regional Ecological Test Site (CARETS) which embraces the Chesapeake and Delaware Bays and urbanized hinterlands. This project will serve as a model of an integrated regional land-use information system. The system encompasses both inventory of the land resource base and monitoring of changes, along with their effects on the quality of the environment. CARETS has stressed potential user receptivity of land-use information systems, involving both the analytical products developed from new remote-sensing monitoring systems, and the experimental integration of contributions from the Geologic, Topograpic, and Water Resources Divisions of the USGS as they relate to the needs of a developing national land-use policy program. Data sets on current land uses, and land use changes, are being derived from remote-sensing sources. Maps and land-use data sets are aggregated by both planning and environmental regions and channeled to a community of users through an experimental regional information center. Evaluations, in terms of regional priorities, are then used to feed back revised requests for remote-sensing data and land-use analysis and to improve the ability to respond to regional information needs. The regional delineation of CARETS was based upon consultation with State and Federal agencies.

Land-use mapping for about one-fourth of the CARETS area has been completed and transferred to rectified mosaic bases with UTM grid. The photomosaic base, at a scale of 1:100,000, has been completed for the entire CARETS region and has a 1-km-square grid overlay keyed to the coordinates of UTM Zone 18.

Using the first two levels of a land-use classification scheme developed by the Interagency Steering Committee on Land-Use Information and Classification, land use mapping of the CARETS area will be completed during 1972.

The Norfolk-Portsmouth Standard Metropolitan Statistical Area (SMSA), in the extreme southeastern part of CARETS, was chosen as a test area for developing the analytical procedures to be used in the rest of the region. To date, the work has included land-use mapping of the Norfolk-Portsmouth SMSA at the first two levels of land-use classification from 1970 photography, mapping of land use from 1959 photography, the assessment of land-use change over the decade corresponding to the decennial census, development of a preliminary land-use–environmental impact model, and coordination of work underway for this project in the Geologic and Water Resources Divisions of the USGS. Urban and built-up land increased dramatically from 15 percent of the total SMSA land area in 1959 to 21 percent in 1970. Geological assessment of present and potential land use stresses the relationships among surficial materials, rock types, topography, land stability, and changing patterns of land use. Hydrologic evaluations of land-use patterns and land-use changes are made in terms of water quantity, quality, and sediment yields.

The developing land-use–environmental impact model is being tested to relate changing land-use and land-surface characteristics with the most critical elements of regional hydrology and climatology and to assess water- and air-quality impacts of land-use changes.

Coordination with potential users has been chiefly made with those who are most critically involved with land-use decisions which these data and analyses may affect. Several planning agencies located in parts of the CARETS region have reviewed preliminary products and have provided recommendations on how those products may be made most useful to them. These agencies include the Metropolitan Washington Council of Governments, the Southeast Virginia Regional Planning District, the city of Norfolk, and the Maryland State Planning Office. A design for systematically expanding the participation of other potential users in the evaluation process has been completed and includes the establishment of an experimental regional information center for CARETS in the USGS Geographic Applications program office. The CARETS Information Center has available a variety of remote-sensing data from NASA and other sources as well as maps, ground-truth data, analytical studies, and user evaluations necessary to help users interpret and analyze remote-sensing data appropriate to the problems of the CARETS region.

Computerized land-use mapping: Phoenix pilot project

A pilot project has been successfully completed to demonstrate the feasibility of computerizing land-use and related environmental data and of plotting out such data on a 1:250,000-scale map base. This project was done for the standard Phoenix quadrangle in Arizona, where many photographs taken from satellite or high-altitude aircraft were available. Interpretation of these high-altitude and space

photographs and maps provided information which was then fed into a digital computer. The digitized information includes land use, land ownership, soils, drainage, and codes for State, county, and census tract identification. All data points were located by UTM coordinates which can be converted automatically to latitude and longitude or to State plane coordinates. Land-use maps have been produced in color, utilizing automatic plotting procedures. Selected words and other fixed patterns from the black plate of the standard quadrangle were overlain on the automated map in order to economize on cartographic costs.

The second phase of the project, change detection and trend analysis, has been started, and the data bank for the Phoenix quadrangle has been updated using recent high-altitude aerial photographs. Interpretation of high-altitude photographs has been performed as a preliminary step in a change-detection experiment which will eventually use data from the ERTS-A. The computer model facilitates study of changing inventories of land uses.

To test the procedure in different environments, work has commenced on two additional 1:250,000 quadrangles: Springfield, Mo., and Russell, Ark.

INTERNATIONAL PROGRAM OF THE U.S. GEOLOGICAL SURVEY

Scientific and technical cooperation with earth resources agencies and institutions in other countries has been an important part of the USGS program for more than three decades. This cooperation has involved technical assistance to developing countries on behalf of the U.S. Department of State, cooperative research and scientific exchange on earth resources problems of mutual concern to the United States and other countries, representational activities with international organizations, and scientific unions, and study or training programs for scientists from abroad.

Technical assistance has long been the principal component of the USGS international program. During 1971, the USGS continued long-range multidisciplinary assistance programs in Afghanistan, Brazil, Colombia, India, Indonesia, Liberia, Nepal, Pakistan, Saudi Arabia, and Turkey, and provided other assistance as indicated in table 2. This assistance is provided under the authority of the Foreign Assistance Act of 1961, as amended, in cooperation with the U.S. Department of State and at the request of the host governments. Most of these programs are sponsored by the USAID. In addition, the USGS had 18 employees on detail to international organizations under the authority of the Federal Employees International Organization Service Act (Public Law 85-795, as amended).

In response to the President's message to Congress on September 8, 1970, the USGS was involved in a number of special program and policy studies during 1971 as part of an effort to increase the application of science and technology in the foreign assistance program. At the request of the USAID, the USGS participated in three workshops to help define the future role of science and technology as applied to natural resource problems in developing countries, contributed to a study by the Federal Council of Science and Technology of new initiatives in international science and technology, participated in a review of space technology applications to earth resource programs abroad by the National Academy of Sciences, and formulated proposals for research on new mapping and exploration techniques specifically applicable to developing countries as a basis for redirecting international assistance programs.

A growing recognition of the potential value of remote-sensing systems for use in earth resources surveys of developing countries led to a rapid increase in cooperative activities in this field during 1971. USGS scientists helped plan and conduct the Seventh International Symposium on Remote Sensing of the Environment held at Ann Arbor, Mich., May 17 to 21, 1971. The USGS also conducted a seminar on remote-sensing applications involving earth scientists from Iran, Pakistan, and Turkey which was held at Ankara, Turkey, from November 10 to 13, 1971, under the auspices of the USAID. In addition, the USGS entered into an agreement with the Inter-American Geodetic Survey to participate in a regional training facility on remote sensing for Latin America. Survey scientists prepared, or helped foreign scientists prepare, more than 20 proposals for experimental applications of earth resources satellite data in other countries and assisted the NASA in the evaluation of proposals. USGS representatives participated in studies by multidisciplinary teams in Mali and the Philippines to define remote-sensing programs and satellite data experiments, helped Brazil organize a remote-sensing program for mineral surveys, conducted remote-sensing surveys for water resources in Jamaica, and participated in symposia on remote sensing in Argentina, Brazil, Venezuela, and Panama.

Scientific cooperation in the study of natural disasters and related phenomena in other countries continued to involve the USGS. A cooperative investigation of the results of the exceptionally disastrous earthquake and debris avalanche of May 31, 1970, in northern Peru (George Plafker and others, 1971) led to USGS participation in a pilot study of the problems of siting and construction in earthquake-prone areas in Peru and Turkey, a study conducted by the U.S. Bureau of Standards on behalf of the USAID. The USGS provided a team to investigate the potential dangers of eruptive activity at Soufriere volcano on St. Vincent Island, British West Indies, and undertook to help Turkey, Iran, and Pakistan develop a coordinated program of tectonic studies related to earthquakes and crustal deformation. During May 1971 a number of USGS scientists participated in a conference sponsored by the North Atlantic Treaty Organization at San Francisco on mitigation of earthquake hazards and postearthquake rehabilitation; more than 170 representatives from 21 countries attended.

USGS cooperation with other countries in marine studies was greatly expanded in 1971. Investigations were carried out cooperatively with Mexico, Honduras, Venezuela, and Liberia under the auspices of the National Science Foundation. A study of geologic conditions related to mineralization in the Red Sea rift was conducted on behalf of the Government of Saudi Arabia, through the U.S. Department of State and with the help of the WHOI. USGS scientists also made a preliminary study of possibilities for geologic mapping of offshore areas in

Table 2.—*Technical assistance to other countries provided by the USGS during fiscal year 1972*

Country	Type of activity[1]	USGS specialists assigned to other countries		Scientists from other countries trained in the United States	
		Number	Type	Number	Field of training
Latin America					
Argentina	B, C	2	Hydrologist	1	Sedimentation.
		1	Sedimentologist		
Brazil	A, C	6	Geologist	4	Economic geology.
		1	Hydrologic engineer	1	Analytical techniques.
		5	Hydrologist	1	X-ray spectrometry.
		1	Geophysicist	1	Fire assay.
		1	Metallurgist	1	Remote sensing.
		1	Mining engineer	3	Geochemical procedures.
		3	Chemist	1	Geology and geologic administration.
				2	Geochemistry.
				2	Laboratory management.
				5	Minerals exploration.
				2	Computers in earth sciences.
				1	Geology.
				3	Water resources—operation, management, and planning.
				1	Hydrology.
				1	Nuclear geology and geophysics.
Chile				1	Engineering geology.
Colombia	A	6	Geologist	6	Economic geology.
		2	Driller	4	Chemistry.
		1	Spectrographer	3	Geochemistry.
Ecuador				1	Hydrogeology.
Guyana				1	Hydrologic data collection and analysis.
				1	Chemistry and analytical techniques.
Jamaica				1	Surface water.
				1	Hydrology.
Panama				1	Analytical chemistry.
Peru	B	1	Geologist		
Africa					
Egypt (U.A.R.)				1	Geochemistry.
Ethiopia	B	1	Ground-water geologist	1	Hydrology.
Kenya	B	1	Ground-water geologist	1	Range water development and hydrology.
		1	Geophysicist		
		1	Electronic technician		
Lesotho				1	Laboratory techniques and rock analysis.
				1	Engineering hydrology.
Liberia	A, C	15	Geologist	1	Geophysics.
		2	Geophysicist	1	Petrology.
		1	Cartographer		
		1	Cartographic technician		
		1	Clerk-typist		
		1	Administrative assistant		
Nigeria				1	Hydrogeology (analog model).
Somalia				1	Hydrogeology.
Tanzania	B	1	Hydrologist		
Uganda				2	Surface-water measurements and instrumentation.
Near East–South Asia					
Afghanistan	A, B	3	Hydrogeologist	2	Surface water.
India	A, B	2	Hydrologist	2	Hydrology and ground water.
		1	Geologist	2	Hydrogeology.
		1	Ground-water geologist	3	Hydrology and drilling.
		1	Ground-water hydrologist	1	Exploration for radioactive materials.
				2	Cartography.
				1	Operation, design, and maintenance of nuclear logging equipment.
				2	Ground water.
				1	Water chemistry.
				1	Hydrochemistry.
Iran				1	Water resources and sedimentation.
				2	Water quality and sediment studies.
Jordan				3	Engineering geology.
				1	Geological engineering ground water.
Nepal	A	1	Ground-water hydrologist	1	Ground-water investigations and water chemistry.
		1	Hydrologist	3	Ground-water hydrology.
Pakistan	A	1	Geologist	1	Geology and laboratory techniques.
		6	Hydrologist	3	Geohydrology.
		1	Ground-water geologist	2	Minerals exploration and mining administration.
		1	Ground-water hydrologist	1	Surface-water hydrology.

Table 2.—*Technical assistance to other countries provided by the USGS during fiscal year 1972*—Continued

Country	Type of activity[1]	USGS specialists assigned to other countries: Number	USGS specialists assigned to other countries: Type	Scientists from other countries trained in the United States: Number	Scientists from other countries trained in the United States: Field of training
Near East—South Asia—Continued					
Saudi Arabia	A	20	Geologist	3	Geology.
		2	Geophysicist		
		2	Administrative officer		
		1	Mathematician		
		2	General services officer		
		4	Cartographic technician		
		1	Computer scientist		
		2	Driller		
		1	Publications editor		
		2	Chemist		
		2	Cartographer		
		1	Geologic cartographer		
		1	Property officer		
		1	Electronic technician		
		1	Physical science administrator		
		1	Secretary		
Turkey	A	3	Geologist	1	Spectroscopy.
		1	Cartographic technician	1	Applied geochemistry.
		1	Lithographic pressman	1	High-level photographs and cartography.
		1	Photographer	1	Mineral exploration.
Far East					
Indonesia	A	9	Geologist	1	Mineral economics.
		2	Cartographer	1	Petrology and ore microscopy.
		1	Librarian	1	Techniques of chemical analysis.
				1	Administrative and technical aspects of geological mapping.
Japan				1	Estuarine research.
				1	Sedimentology.
Korea				1	Ground water.
Republic of China				1	Exploration for radioactive materials.
				1	Land subsidence and ground water.
				1	Hydrology.
Thailand				1	Water-resources development.
Vietnam	C	1	Sedimentologist		
Other					
Austria	C	1	Hydrologist	1	Geochemical exploration.
Bulgaria	C	1	Geologist		
Canary Islands	C	2	Hydrologist		
		1	Physical scientist		
France	C	1	Hydrologist	1	Geochemistry and geology.
Germany				1	Micro-earthquake studies.
Greece	C	1	Hydrologist		
New Zealand				1	Crustal deformation.
Poland				1	Water-resources development systems.
Rumania				1	Stream gaging.
Spain	C	2	Hydrologist	1	Digital modeling of ground water.
Switzerland	C	1	Hydrologist		
Yugoslavia	B, C	2	Geologist		
		1	Hydrologist		

[1] A, broad program of assistance in developing or strengthening earth-science institutions and cadres including geologic mapping and appraisal of resources; B, special studies of geologic or hydrologic phenomena or resources; C, short-range advisory help on geologic or hydrologic problems and resources.

Indonesia and a study of possibilities for cooperative marine resource investigations in Spain.

An extension of the USGS domestic research program into Poland and Yugoslavia was made possible through congressional authorization for Interior Department use of local currencies owned by the United States in those countries under provisions of Public Law 480. USGS representatives participated in an interagency team visit to Poland and Yugoslavia in April 1971, during which possibilities for a number of cooperative research projects of mutual interest were identified in discussions with counterpart earth-science institutes.

The USGS continued to have an active role in many international organizational affairs, exchange programs, and scientific unions. Dr. Thomas B. Nolan, former Director of the USGS continued to serve as Vice President of the International Union of Geological Sciences; Dr. Arch Gerlach, until his death, was President of the Pan American Institute of Geography and History; and Mr. William A. Radlinski, Associate Director, was recently elected the President of the

Federation Internationale de Geometrics. Mr. Rupert B. Southard, Jr., Associate Chief Topographic Engineer, is the U.S. Representative on the Work Group on Geodesy and Cartography of the Scientific Committee on Antarctic Research, U.S. National Academy of Science, National Research Council, sponsored by the International Council of Scientific Unions. USGS specialists continued to participate actively in many commissions of the International Union of Geological Sciences, such as the Commission for the Geologic Map of the World, and in activities associated with the International Union of Geodesy and Geophysics (IUGG). Twenty-four USGS scientists participated in the IUGG meeting in Moscow from June 30 to August 14, 1971, which had approximately 3,000 representatives from 58 countries. Hydrologists of the USGS also continued to participate in the activities of the IHD.

The USGS continued to help arrange and conduct training or study tours in the United States for participants and visitors from other countries. All parts of the USGS were involved in these activities during fiscal 1972. A total of 122 participants sponsored by United Nations agencies, the USAID, foreign governments, other international organizations, and special fellowship funds came from 36 countries during the year. Types of assistance given each country during the fiscal year are summarized in table 2. To date, 1,278 participants from 84 countries have completed research, observation, academic, or intern training programs in the United States under USGS guidance.

Since the beginning of the USGS technical assistance program in 1940, more than 1,710 technical and administrative documents authored by USGS personnel have been issued. During calendar year 1971, 136 administrative and (or) technical documents were prepared, and 83 reports were published or put on open file. (See table 3.)

Table 3.—*Technical and administrative documents issuing in calendar year 1971 as a result of the USGS technical assistance program*

Country	Administrative and project reports	Reports or maps prepared		
		Approved for publication by USGS and counterpart agencies	Published in technical journals	Published or released by USGS
Argentina	3	1	....	....
Brazil	25	5	8	3
Ceylon	2	....	....	....
Colombia	9	4	5	2
Costa Rica	2	1	....	....
Ethiopia	1	....	....	....
Guyana	....	....	1	....
India	5	....	....	1
Indonesia	10	6	2	2
Iran	....	....	1	....
Israel	1	....	....	....
Jamaica	3	....	....	....
Liberia	27	24	9	21
Nepal	2	....	....	1
Nigeria	1	....	....	....
Pakistan	8	4	....	4
Paraguay	1	1	1	....
Saudi Arabia	6	28	12	6
Spain	2	....	....	....
Taiwan	2	1	....	1
Thailand	4	....	....	1
Turkey	12	3	....	....
Vietnam	1	....	....	....
General	9	4	1	1
Total	136	82	40	43

SUMMARY BY COUNTRIES

Unless otherwise stated, the work described below was sponsored by the USAID, U.S. Department of State, and the Government of the cooperating country through its earth-sciences institutions.

AFGHANISTAN

Evaporite deposits

Seven areas considered favorable for evaporites other than salt were evaluated in 1971 by G. I. Smith. None appears to have significant percentages of potash. Dashte Nawar, a closed basin 55 km west of Ghazni, contains sediments whose pore brines are moderately high in sodium carbonate, but the sediment porosity is probably too low to allow large-scale production. Brines in Namaksar Tashqurghan (Sar-i-Namak), a small salt-filled deflation depression northwest of Tashqurghan, contain nearly 100 ppm lithium, but this concentration is about one-fourth of the concentration in the major lithium-brine operation in the United States, and the area is not well suited to the construction of solar evaporation ponds, which would be the most likely method of extraction.

Reconnaissance for phosphate deposits

D. F. Davidson carried out a reconnaissance of parts of Afghanistan known to contain Devonian, Permian, and Cretaceous marine rocks in an attempt to find evidence of geologic environments that were suitable for the deposition of phosphate deposits. Only one such sequence of rocks was found. A Permian sequence northwest of Ghazni consists of thin interbedded carbonate rocks and chert. No phosphorite is associated with it. Nearly all other sequences are flysch facies where deposition took place in shallow water and at a very rapid rate of accumulation.

Ground-water reconnaissance in the Arghandab River basin near Kandahar

E. A. Sammel, reporting on a recently completed ground-water reconnaissance in the Arghandab River near Kandahar, noted that (1) accumulated deficiency in precipitation during the period 1960–70 resulted in below-normal streamflow as well as a regional decline in ground-water levels in southwest Afghanistan, and (2) the critical shortage in the surface-water supply during 1970–71 caused attention to be focused on the ground-water potential of the region as a supplementary

source of water for long-term irrigation requirements. He estimated that (1) water-saturated alluvium in the Kandahar area may be several hundred meters thick, (2) annual recharge to the ground-water reservoir in the area may be about 665 million m^3, (3) average net discharge of ground water to streams of the area may be about 560 million m^3 annually, (4) withdrawals from wells and karezes was about 38 million m^3 in 1971, and (5) direct evapotranspiration from ground water may be in the range of 35 to 70 million m^3 annually. Concentrations of dissolved solids in ground water from wells, karezes, and drains of the area range from 300 to 10,000 mg/l.

ARGENTINA

National water-data system for Argentina

W. W. Doyel, during a 1-month assignment in 1971 for the Organization of American States, worked with the Argentine Secretaría de Recursos Hídricos to establish guidelines for a national water-data system. He recommended the scope, objectives, and methodology for an integrated water-data system that would include all major parameters in streamflow, ground water, lakes and reservoirs, sediment, water quality, and water use.

Reconnaissance of dam and reservoir sites in upper Río Bermejo basin

Reconnaissance field examinations of 17 potential dam and reservoir sites in the upper Río Bermejo basin of northwest Argentina were completed in 1971 by Ted Arnow during a 3-month assignment with the Organization of American States. At each site he evaluated rock permeabilities with respect to potential reservoir water losses; dam foundation conditions; geologic features including faults, fracture zones, and unstable rock masses that might slide into reservoirs after impoundment; and availability and physical characteristics of local construction materials. Most of the sites were judged to be physically favorable, but without upstream control several sites would have an individual reservoir life of less than 100 yr.

ARGENTINA AND CHILE

Portable mercury vapor detector with an integral thermoamalgamator

A USGS model mercury vapor detector, described in USGS Circular 540, was constructed in the geological laboratories of the Instituto de Investigaciones Geológicas, Santiago, Chile. A similar instrument was also installed in the Dirección Nacional de Geología y Minería, Tucumán, Argentina. Local personnel from these institutions were selected to work with W. W. Vaughn and Robert Weir; both instruments were put into operation, checked for reliability, and calibrated. The instrument is transistorized, battery powered, and has a built-in thermoamalgamator. It weighs about 7 lb and can be operated by one man in the field.

BRAZIL

Chromite at Campo Formoso, Bahia

D. C. Hedlund reports that metamorphosed ultramafic rocks of pre-Minas age crop out in an elongate belt measuring about 1 by 15 km along the west side of the Serra de Jacobina near Campo Formoso. The original stratiform ultramafic rocks have been eroded, faulted, and metamorphosed to such an extent that only dismembered segments can be found along the west side of the Serra de Jacobina. The most important segment is that near Campo Formoso where economically valuable chromite-bearing layers of metallurgical grade near the base of the intrusion can be followed for about 8 km.

The thick section of chromitite suggests that the original stratiform complex was at least 3 to 4 km thick (T. P. Thayer, 1970, unpub. data). Because most of the complex is concealed by the overlying thrust plate of Jacobina quartzite and phyllite, the amount removed by prequartzite erosion is unknown. The presence of detrital chromite in the quartzite of the Rio de Ouro Formation, however, suggests that erosion may have extended as deep as the chromititic zone within the lower part of the complex.

It was discovered that ground magnetic traverses were useful in delineating and establishing the continuity of concealed chromite layers, and sharp magnetic anomalies were observed over exposed chromitite layers that dip 40° to 65°. Magnetic susceptibility measurements (K values) of fresh chromitite samples indicated a range from 0.017 to 0.119 emu/cm^3. Petrographic studies reveal that most of the chromitite layers contain chromite with ferrichromite rims. This zoning is the result of metamorphism and suggests that the outer zones are enriched in iron due to the replacement of Mg^{+2} and Al^{+3} by Fe^{+2} and Fe^{+3}. Kammererite mantles around some of the chromite-ferrichromite grains suggest a transfer of Cr^{+3} and Al^{+3} from the outer margins of the chromite grains into the interstitial serpentine to form chrome chlorite.

Three to five chromitite layers of minable thicknesses have been mapped, the thickest being about 1.8 m. Total aggregate thickness of minable chromitite is about 5 m. Minable chromitite will probably be greatly reduced because of the extreme faulting and offsetting of the chromitite layers and presence of thick colluvial cover locally. The Cr:Fe ratio ranges from 1.07 for weathered friable chromite to as much as 2.80 for the massive nonweathered variety.

Platinum investigations in Goiás

Previous work undertaken by R. W. White (USGS), Jorge Motta, Kiomar Oguino, and V. A. Araújo, Companhia de Pesquisa de Recursos Minerais (CPRM) in ultramafic rocks of the Tocantins complex, near Niquelandia, Goiás, revealed the

presence of platinum metals in chromitite. Chemical studies of the material led to the general conclusion that some or all of the platinum metals are dispersed in solid solution in the chromite and require chemical processing for recovery.

Coarse gravel derived from mafic and ultramafic rocks of the Tocantins complex has been deposited in an alluvial plain that covers an area of 200 km^2 east of the complex. Platinum metals were detected chemically in six heavy-mineral concentrates collected at the west edge of the alluvial plain, in amounts representing 0.0003 to 0.0008 g/ton of gravel. Attempts to isolate a platinum-rich mineral or alloy in the concentrates were unsuccessful, as have been earlier attempts with samples of platinum-bearing chromitite from the ultramafic zone of the complex.

Hydrologic data collection and analysis

Plans were completed for a program to compute and compile about 15,000 station years of streamflow records collected in Brazil since 1920. W. W. Evett and D. C. Perkins, USGS hydrologists, prepared a report that is being used as a guide in analysis of historical data and specifies the division of workload for various agencies involved in analyzing the data. As a result of studies made by W. L. Isherwood and M. D. Edwards, USGS data-processing specialists, during short assignments in Brazil, the Ministry of Mines and Energy has contracted with a private company to equip the new Automatic Data Processing Center. Isherwood recommended the configuration of computer equipment, and Edwards recommended designs for the software and hydrologic information systems as well as a training program for personnel.

CPRM was given the responsibility for all field operations in the collection of hydrological data, including the installation and maintenance of equipment. Staffing of the CPRM, including Agency Offices in Belém, Recife, Belo Horizonte, Goiania, São Paulo, and Porto Alegre was completed. The Departamento Nacional de Águas e Energia Eléctrica (DNAEE) is responsible for planning and the analysis and publication of data. Plans were completed by DNAEE for a general upgrading of the network by installation of automatic recording equipment.

CENTO

Studies of phosphate deposits

The Central Treaty Organization (CENTO) Working Group on Phosphate Deposits visited known phosphate deposits in Turkey, Iran, and Pakistan during the fall of 1971. D. F. Davidson, U.S. Coordinator, reports that each of the countries has one or more deposits that deserve careful evaluation as potential sources of phosphate. A report describing known deposits is being prepared for publication by CENTO.

Training

The sixth annual CENTO training course in geologic mapping, mineral exploration, and mineral deposit evaluation was conducted from July 20 to September 22 at the Ergani copper mine in eastern Turkey under the direction of E. H. Bailey (USGS). Other instructors were M. P. Nackowski (Univ. Utah), J. W. Barnes (Univ. Wales, Coll. Swansea, United Kingdom), Mehmet Yildiz (Maden Tetkik ve Arama Institüsü Turkey), and briefly, Asad Iranpanah (Tehran Univ., Iran).

Eighteen postgraduate trainees from Turkey and Iran participated in the systematically programmed course in modern field methods used in studying mineral deposits. The large open pit of the Ergani mine, the major source of copper in Turkey, was mapped in detail by planetable methods, the surrounding area was mapped on a topographic base, and geochemical testing was done in a selected area. These studies yielded maps of immediate value to the mine operator and new concepts regarding the emplacement of the massive sulfide ore as well as practical training to the program participants. A report containing the maps and conclusions derived from them is being prepared for publication by CENTO.

Remote sensors seminar

R. W. Fary, Jr., organized and conducted a "Seminar on Applications of Remote Sensors in the Determination of Natural Resources" for the CENTO countries. The seminar was held in Ankara, Turkey, at the Mineral Research and Exploration Institute. Participants included 10 scientists from Iran, 13 from Turkey, one from the United Kingdom, eight from the United States, and approximately 100 observers from Turkey, the United Kingdom, and the United States.

INDONESIA

Tectonic map

The tectonic map of Indonesia, compiled in the context of plate tectonics, includes data of paleoenvironmental significance and indicates continuity of tectonic belts of varying types and age and thus is useful in assessing different terranes for metals or petroleum potential. For example, the plate-tectonic analysis suggests that the oil-bearing Sumatra Tertiary basin does not continue eastward across the Sunda Shelf north of the west coast of Java but rather fans out eastward into several thinly filled and obliquely superimposed basins.

Geologic mapping

In central Java the pre-Tertiary rocks have been divided by K. B. Ketner and associates into two units: a nonmetamorphic sequence that includes shale, sandstone, conglomerate, chert, and limestone and a melange composed of blocks of the

nonmetamorphic sequence mechanically mixed with blocks of phyllite, schist, metaquartzite, gabbro, peridotite, and serpentine. The melange has been thrust over the nonmetamorphic sequence, and the whole assemblage has been gently folded and broken by high-angle faults. Fossils in a limestone block within the melange indicate a Cretaceous age. Both the nonmetamorphic sequence and the melange are overlain unconformably by Eocene conglomerate, which contains pebbles of metamorphic rocks. The melange therefore formed in very Late Cretaceous or very early Tertiary time.

The pre-Tertiary rocks of west-central Sumatra are composed largely of volcanic material, phyllite, quartzite, and marble. Pennsylvanian, Permian, and Triassic fossils have been identified, but much of the assemblage remains undated. Because the undated rocks resemble the miogeosynclinal lower and middle Paleozoic rocks of western Malaysia, Keith Robinson and associates conclude that a complete Paleozoic sequence is probably present in west Sumatra.

Mapping by Indonesian geologists aided by K. B. Ketner reveals similar tectonic phenomena in Java and Sulawesi (Celebes). Middle Tertiary limestone formations in both areas have been thrust over slippery clay units. Huge blocks of limestone subsequently have broken loose and, under the influence of gravity, have drifted far from the outcrop. Now they form isolated buttes completely surrounded and underlain by clay. Elsewhere in Java, a block of Pliocene conglomerate 5 by 10 km in extent has slid at least 10 km on a bed of clay.

Reconnaissance for tin deposits

A brief field reconnaissance was made by M. R. Klepper and W. F. Hanna (USGS), and Mohamad Untung (Geological Survey of Indonesia) in the Pemali tin district, Bangka, Indonesia, to investigate possibilities of geological and geophysical exploration for primary tin deposits. Density and magnetization measurements of surface rocks indicated that contrasts may be insufficient to warrant extensive gravity and magnetic surveying. It was suggested, in view of observed geological relations, available base maps, ambiguous geological literature, and cost of operation, that a limited pilot survey using resistivity, gravity, and magnetic methods be made in a test area near one of the most actively mined pits in the district to determine the value of further exploration using these geophysical techniques.

Training in geophysics

An integrated geophysical survey in an area of iron-rich black sand deposits along the southeast coast of Java was conducted by Mohamad Untung and other geophysicists of the Geological Survey of Indonesia under the direction of W. F. Hanna as a field exercise in a training course. The survey combined vertical-intensity magnetic, horizontal-intensity magnetic, total-intensity magnetic, gravity, radiometric, resistivity, seismic refraction, portable magnetic susceptibility, and bulk density measurements on a topographically surveyed 50-m grid. Gravity, resistivity, and seismic data indicate the presence of a north-south undulating bedrock floor beneath the sand, possibly reflecting a buried north-south drainage pattern. Magnetic data show that the most highly magnetic sands occur in four crescent-shaped belts parallel to the coastline, two of which are partly exposed and two of which are covered by alluvium, vegetation, or construction. Chemical analyses of the black sand indicate that its titanium content is sufficiently low for profitable exploitation of the iron by means of modern refining techniques.

A gravity reconnaissance in the Dieng Plateau geothermal area, central Java, also conducted by Mohamad Untung and geophysicists of the Geological Survey of Indonesia, was made partly under the direction of W. F. Hanna. Two 10-mgal Bouguer gravity minimums were identified, one correlating with a previously measured resistivity low. They indicate relatively abundant low-density volcaniclastic material in the shallow subsurface.

Chemical prospecting for geothermal energy in the Dieng Mountains

A. H. Truesdell made a geochemical survey of surface springs and fumaroles in the Dieng Mountains, central Java, Indonesia. The results indicate that the geothermal systems will produce hot waters and steam rather than steam alone. More than one near-surface system exists with possible connections at greater depths. The largest of these systems is the Pagerkandang system which is at least 2.5 km^2 in area. These systems have not formed boiling hot springs as at Yellowstone Park (U.S.A.) or in New Zealand, but they give rise to very active fumaroles and contribute chloride to warm springs at lower elevations offset from the centers of activity. The subsurface temperatures indicated by the chemistry of available fluids are 200°C or greater. No problems are anticipated from corrosion or pollution. The rate of heat production and size of the systems suggest a valuable energy resource.

LIBERIA

Map compilation

The folio of Liberia, now in final stages of compilation, will be a major product of the Geologic Exploration and Resource Appraisal project (GERA) that the USGS has been conducting in cooperation with the Liberian Geological Survey (LGS) since 1964. The folio will consist of a series of maps for 10 quadrangles, 1:250,000 scale, showing geography (shaded relief base maps), geology, aeromagnetic and total-count gamma-radiation data, gravity (for one quadrangle), and mineral-resource information. It is designed to allow for addition of categories of maps that may result as the LGS continues to develop and to expand the scope of its activities.

The geographic shaded-relief base maps, constructed by the project when planned topographic maps were indefinitely delayed, are being published at 1:250,000 scale. In addition, form-line sheets at 1:40,000 and 1:125,000 scale, produced at intermediate stages in the construction of the shaded-relief maps, will be available for limited distribution in Liberia to interested government agencies, private organizations, and the public. These form-line sheets are available now in preliminary form and have already found widespread use in agriculture, forestry, urban and rural planning, lumbering, engineering, the military, and many other fields. It is expected that the shaded-relief maps will continue to meet a need even after topographic maps of Liberia become available.

Airborne magnetic and total-count radiometric quadrangle maps covering Liberia (J. C. Behrendt and C. S. Wotorson, 1971a-s; Wotorson and Behrendt, 1971a-c) are available in open file at 1:125,000, 1:250,000, 1:500,000, and 1:1,000,000 scale; publication scale is 1:250,000. These preliminary maps have been used extensively in resources exploration. The magnetic maps, in particular, have played an important part in stimulating and in planning offshore exploration for oil. Digitization and computer processing of the magnetic and radiometric data will result in refined or special-use maps for further work in resources appraisal; near-surface magnetic maps for most of the country are now available in preliminary form at the LGS.

The geologic maps are based on reconnaissance mapping by the project staff, supplemented by photogeologic, aeromagnetic, radiometric, and gravity data as well as field data from mining companies and other sources outside the project. Field compilation was completed in July 1972. Preliminary results of the mapping program and topical reports prepared during the course of the project have been used widely by companies and individuals in minerals exploration.

Geology

Boundaries of age provinces previously delineated largely on geophysical and spot radiometric analyses can now be more precisely tied to the surface geology on the basis of mapping by USGS and Liberian geologists. The northwest boundary of the Eburnean age (2,000 m.y.) province has been tentatively correlated with a major northeast-trending shear zone in the Juazohn quadrangle by R. G. Tysdal; northwest of it is a zone of rocks (2,000–2,700 m.y.) transitional to the Liberian age province (2,700 m.y.). Mapping in the Harper quadrangle by M. R. Brock and A. H. Chidester has substantiated and extended this major shear zone southwestward to the sea near Grand Cess.

Eric Force, R. G. Tysdal, and C. H. Thorman, mapping in separate quadrangles, have recognized a northwest-trending major shear, extending from near Greenville into Sierra Leone, that is the boundary between the Liberian age province and the Pan-African province (550 m.y.). In the Monrovia quadrangle, Thorman has found especially good evidence of the nature of this major contact zone of mylonitic rocks. Foliation of the mylonitic rocks everywhere dips 30° to 60°SW. beneath the Pan-African age province. Foliation in both provinces is generally steeper than 70°; thus the shear zone is discordant to the structure of both provinces but is parallel to Pan-African trends. The Pan-African rocks have probably been thrust northeast over those of the Liberian age province. Gravity data interpreted by J. C. Behrendt and C. S. Wotorson (1971s) show the strong gradient seaward of the shear zone and support the interpretation of a southwest-dipping contact between the two provinces.

Thorman has found an outlier of Pan-African quartzite, iron-formation, and schist at Gibi Mountain (loc. 8, index map) about 25 mi northeast of the shear zone, which supports the theory of large-scale thrusting. The outlier is thrust over conglomerate, arkose, and shale, which are presumed to be middle Paleozoic and to lie disconformably on Liberian-age granodiorite gneiss. The thrusting is no younger than Early Jurassic, as dikes of that age cut the thrust.

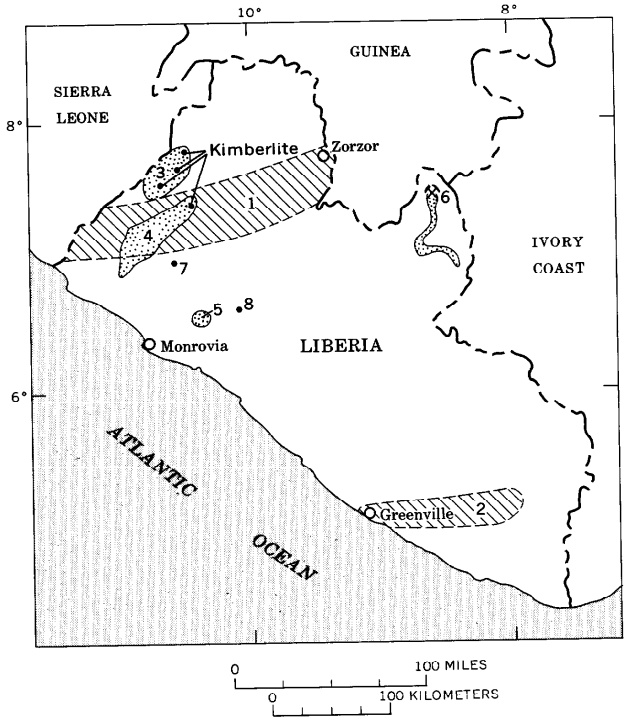
The root zone for the Gibi Mountain thrust is thought to be the shear zone separating the Pan-African and Liberian provinces. First, structural and geophysical data on the attitude of the shear zone and the direction of overturning of folds at Gibi Mountain are consistent with such an interpretation. Second, iron-formation and quartzites in the Pan-African province more closely resemble the allochthonous rocks than do any in the Liberian province although they are far from exact correlatives. Assuming the correlation of structures is correct, the Pan-African province has been thrust over the Liberian province in excess of 20 mi in the Gibi Mountain vicinity.

The Gibi Mountain klippe and the Pan-African-Liberian shear zone indicate a previously unrecognized major orogenic event in western Liberia that probably occurred in middle to late Paleozoic time.

Mineral resources investigations

Further work by Samuel Rosenblum (USGS) and S. P. Srivastava (LGS) on the phosphate rock deposit near Bambuta (loc. 7), has further clarified some of the geologic relations, and additional drilling by the Liberia Mining Co. has delineated substantial reserves. The deposit is apparently a Precambrian inorganic marine precipitate and underlies an iron-formation with which it was simultaneously metamorphosed. The phosphate minerals are aluminous at the surface (variscite and augelite) but are mainly iron-rich at depth (mainly barrandite, strengite, and phosphosiderite, plus minor wavellite, metavariscite, ferrian variscite, and barbosalite). Data from 25 drill holes indicate minimum reserves of about 1 million metric tons containing about 32 percent P_2O_5, or 1.5 million tons containing about 28 percent P_2O_5.

Several hundred occurrences of placer gold, the sites of many former gold placer operations, diamond diggings, and other mineral commodity data have been located on modern



base maps of Liberia as a part of the GERA project. These data have been compiled by W. L. Coonrad from field observations by the combined USGS and LGS GERA staff and from information contained in old reports and unpublished documents. Geological associations are generally perceivable even though data are sparse in some areas.

One prominent belt (area 1) of gold occurrences extends approximately 150 mi northeast from the western edge of Liberia to the vicinity of Zorzor close to the Guinea border. Another belt (area 2) extends about 85 mi east from the vicinity of Greenville. Most of the historic production of gold (about 100,000 oz) has been achieved by hand methods from shallow placers lying within these belts.

According to Coonrad, the bulk of the diamonds mined in Liberia come from placer deposits. In some areas the placer diamonds are obviously derived from small kimberlite bodies (areas 3 and 4). In other deposits (area 5), the primary sources have not been identified and the diamonds appear to have been transported within modern and ancient drainage systems. In one area, diamonds are mined from a probable sedimentary lode source (loc. 6) as well as from placers derived from the lode. The lode diamonds are extracted by open-pit "gophering" to depths of as much as 30 ft in a schist, some of which is graphitic. The typical kimberlite indicator minerals, picroilmenite and pyrope garnet, have not been recognized in the lode, and the current interpretation is that the lode diamonds are sedimentary clasts of Precambrian age.

Heavy mineral investigations

In a study of more than 2,500 stream- and beach-sand samples, S. P. Srivastava and Samuel Rosenblum have recognized 47 heavy minerals. On the basis of characteristic and unusual features of many of these minerals, five mineral associations have been distinguished:

1. Monazite-sillimanite-corundum-staurolite-gold.
2. Almandite-monazite-rutile-xenotime-corundum-gold.
3. Monazite.
4. Magnetite-monazite-chromite-xenotime-gold.
5. Tourmaline-almandite-cassiterite-columbite.

Continued investigations probably will reveal regional patterns of mineral occurrence that will help in future geologic mapping and that may be indicators for possible economic mineral resources.

Institutional development

In the field of participant training, the GERA project has made a major contribution to the development of a trained staff in the LGS capable of carrying forth a geological program for Liberia. Training in which Liberian geologists worked with American counterparts in the field and laboratory has provided valuable experience for members of the LGS. Under the guidance of Samuel Rosenblum, the mineralogy and petrology laboratories have acquired the basic facilities and a staff of trained personnel necessary to provide the basic support for geological and mineral resources investigations.

NEPAL

Stream-gaging program

In 1971, H. C. Riggs completed a 3-month field review of the stream-gaging program in Nepal. He concluded that (1) operation of most existing stream-gaging stations in the country should be continued for at least 10 yr, (2) some gaging stations should be added to expand geographic coverage, to gage some high-altitude basins, and to provide index stations for transferring low-flow characteristics, (3) the number of partial-record stations should be increased to define low-flow and flood-peak frequency characteristics, (4) shortcut methods could be applied to define monthly flows and flood-channel depths, (5) the special hydrologic studies program should be integrated with the data-collection program so that they complement each other, and (6) the sediment characteristics of Nepalese rivers should be sampled on a reconnaissance basis.

PAKISTAN

Hydrogeochemical appraisals and evaluations in the Punjab region

William Back and R. N. Cherry completed a 2-month appraisal and evaluation of hydrogeochemical problems in the Punjab region of West Pakistan. They noted that three

hydrogeochemical problems exist in the region for which understanding is not yet fully adequate for optimum water management. These are (1) the nature and extent of corrosion and encrustation of tubewells, (2) classification of irrigation waters, and (3) the rate and distribution of salt buildup in the soil and the ground-water system. They recommended that hydrochemical studies in support of hydrologic research be directed toward evaluating (1) the potential deterioration of wells and pumps due to chemical processes, (2) the potential deterioration of water quality, and (3) the significance of the lower boundary of the fresh ground water with respect to its chemical rather than physical nature.

PERU

Huascarán, Peru, debris avalanche

Study by George Plafker and G. E. Ericksen of the disastrous earthquake-triggered debris avalanche from Huascarán Mountain in Peru in 1970 has contributed significant new data on the mechanism of high-velocity landslides and debris flows.

The avalanche, which originated on the north peak of Huascarán Mountain at an altitude between 5,500 and 6,400 m, buried the city of Yungay and part of Ranrahirca (alt about 2,500 m) with a loss of an estimated 25,000 lives. The debris avalanche involved 50 to 100 million m^3 of rock, ice, snow, and soil that traveled 16 km from the source to the inhabited valley below at an average velocity of between 280 and 335 km/hr. Exceptionally rapid movement of the avalanche is indicated by eyewitness accounts, by topographic irregularities as much as 140 m high that were overridden, and locally by boulders weighing several tons that were hurled as much as several kilometers through the air.

The avalanche's extremely high velocity was due primarily to the combination of steep slopes in the source area, a low-friction glacier on which to slide immediately below the source area, and great vertical relief (averaging about 3,500 m) along its 16-km path. In addition, an extremely low effective coefficient of friction of only 0.22 for the moving mass implies that air-layer lubrication or cushioning occurred along much of the avalanche path. The fluidity of the debris and other aspects of this event suggest the possibility that a significant quantity of water was generated near the source almost instantaneously by pressure melting of glacier ice beneath the avalanche.

The Huascarán debris avalanche appears to be an event that, in terms of destructiveness, height of fall, velocity, and probably volume, far exceeds any avalanche known to have occurred during historic times. Nevertheless, there is clear geologic evidence that a considerably larger avalanche from the north peak of Huascarán devastated the same area in pre-Columbian times.

St. Vincent Island, British West Indies

In November the famous Soufriere Volcano, St. Vincent Island, British West Indies, began to show signs of renewed activity after seven decades of dormancy. Recalling the destructive eruption in 1902 when 1,565 were killed, Prime Minister Milton Cato of St. Vincent appealed, through the American Ambassador to Barbados, for USGS scientific and technical assistance in what was a potentially dangerous situation. A USGS team composed of specialists in volcanology and remote sensing, D. A. Swanson, R. A. Bailey, and J. D. Friedman, arrived on the island in late November to assess the volcano's potential for danger to life and property and, if necessary, to recommend an early warning alarm for evacuation of the area. The investigative and surveillance plan involved aerial photography, infrared thermal imagery, and a geodimeter observation system. Cooperating in the effort were USGS staff at San Juan, Puerto Rico, British geologists at Barbados, and scientists of the University of West Indies. The results of the USGS project at year's end are summarized as follows:

1. Thermal surveillance using infrared imagery: (a) no new exit points of thermal waters nor fractures in the volcanic edifice were observed; there was no noticeable increase in flow of streams draining the volcano to account for the lowering in surface level of the water lake and (b) on infrared imagery, the surface of the dome generally appeared to be considerably cooler than the 74° to 79°C nearshore temperature of the lake.
2. Geodimeter studies—measurements taken on several 1-km-long lines to detect swelling or shrinkage of the volcano showed no detectable volume changes.

SAUDI ARABIA

The USGS current program of cooperative work with the Kingdom of Saudi Arabia continued to emphasize training of Saudi Arabian scientists as part of the studies of the Precambrian shield of the Arabian Peninsula.

W. R. Greenwood, D. G. Hadley, Louis Gonzalez, R. G. Coleman, and D. L. Schmidt have undertaken a program based on the premise that a prerequisite to the search for economic mineral deposits on the Arabian Shield must be a thorough knowledge of the Precambrian geology. They have synthesized the Precambrian stratigraphy and structure in the southern part of Saudi Arabia on the basis of geologic relations in 15 30-minute quadrangles that have been geologically mapped at 1:100,000 scale during the past 2 yr under a work agreement between the USGS and the Saudi Arabian Ministry of Petro- and Mineral Resources.

Six major lithostratigraphic units form four stratigraphic sequences bounded by angular unconformities that mark four tectonic events and a younger Precambrian–Early Cambrian major faulting event, the Najd wrench faulting. From oldest to youngest the six stratigraphic units are: the Hali Group

consisting of amphibolite and biotite paraschist commonly of the amphibolite facies, the Baish Group of dominantly basaltic greenstone, the Bahah Group of fine-grained commonly siliceous and basaltic detrital greenschist and greenstone, the Jiddah Group and Halaban Group of dominantly andesitic volcanic and clastic rocks of the greenstone facies, and the slightly metamorphosed Murdama Group, dominantly of metagraywacke but with subordinate marble. In addition, the Khamis Mushayt Gneiss and migmatite may constitute a basement beneath the stratigraphic succession.

The four tectonic events, in ascending order, are the Asir tectonism, involving the Hali and basement rocks; the Tihama orogeny, involving the Baish, Bahah, and older rocks; the Hijaz orogeny, involving the Jiddah, Halaban, and older rocks; and the Bishah orogeny, involving the Murdama and older rocks. In addition, the Khamis Mushayt Gneiss may have had its own complex and older Precambrian tectonic history, but it has thus far not been possible to prove a basement tectonism separate from the Asir tectonism. In fact, the Hali Group and possibly intrusive rocks of Asir age may have been initially deformed and metamorphosed only during the Asir tectonism, in which case the Hali Group and Khamis Mushayt Gneiss together may represent basement rocks.

Igneous intrusion of diorite to trondhjemite and granodiorite to granite is a part of the long interval of the Hijaz orogeny and was largely controlled by and perhaps genetically related to north-south, left-lateral wrench faulting. The older dioritic rocks of this suite are radiometrically dated at about 1 b.y. and are the oldest dates yet determined for the Arabian Shield. Granitic plutonism and north-south wrench faulting continued during the Bishah orogeny. Diapirically emplaced gneiss domes as structural domes and antiforms have high-grade gneissic, chiefly orthogneissic, cores shrouded by Hali-type paraschists and paragneisses and are associated with the north-south faulting that occurred during the Hijaz and Bishah orogenics. Conspicuous plutons of gabbro, many with layered structures, were also intruded during these two events.

During latest Precambrian and Early Cambrian, the deformed Murdama Group and older rocks were refolded and redeformed along northwest-trending left-lateral wrench faults of the Najd fault system in the eastern part of the southern shield region. Small granitic plutons accompanying or slightly younger than the faulting have been radiometrically dated at about 520 to 540 m.y.

Metavolcanic and metasedimentary rocks younger than the Murdama Group, predominantly rhyolitic rocks of the Shammar Group, and detrital and volcanic rocks of the J'Balah Group are respectively slightly older and contemporaneous with the Najd faulting in the northern part of the shield. These rocks have not been found in the southern shield area.

Older Precambrian rocks

Widespread medium- to high-grade metamorphic rocks recently mapped by D. G. Hadley in the Wadi Hali quadrangle of the southern part of Saudi Arabia are some of the oldest rocks of the Arabian Shield. Of these rocks the oldest stratified unit is the Hali Group which is a dominantly metasedimentary unit that has been metamorphosed to the almandine-amphibolite facies. It is composed mostly of amphibolite, tremolite-actinolite-biotite schist, and garnet-biotite gneiss. Dolomitic marble, muscovite schist, and metaconglomerate are subordinate facies of the schist.

Folded with the Hali Group is a moderately to strongly foliated metamorphosed tonalite. The tonalitic gneiss occurs as two large, gently plunging antiforms. These two structures acted as relatively rigid masses during intensive north-south wrench faulting, and strongly influenced the style of folding in the surrounding Hali Group. The tonalite as an orthogneiss may represent an old plutonic phase intrusive into the Hali rocks during the initial deformation of the Hali (Asir tectonism), so that the tonalite and Hali are about the same age, but the evidence for intrusion has been obliterated by subsequent intensive shear faulting.

Alternatively, the tonalitic gneiss may be older than the Hali and represent true basement emplaced diapirically as a geniss dome. A contact-metamorphic aureole in Hali rocks represented by sillimanite, garnet, and hornblende mineral assemblages crosses the north-south shears in a way to be expected if a "hot" gneissic mass younger than at least the adjacent north-south shearing in this area had been emplaced.

These two alternatives emphasize the problem of whether the Hali Group and associated crystalline gneiss masses are together a single basement unit or whether the Hali overlies an older gneissic basement.

Chemistry of Precambrian plutonic rocks

W. R. Greenwood and G. F. Brown have interpreted chemical analyses and normative calculations of late Precambrian plutonic rocks from the Arabian Shield to indicate two major intrusive series: an older calcic series of diorite to trondhjemite and a younger calc-alkalic series of granodiorite and granite. It is suggested that the potassic rocks are not a simple differentiate from the magma that produced the dioritic rocks but are a different magma series.

Potassic plutons are most abundant in the northeast part of the shield, as shown by measurement of plutonic rock distribution on geologic maps of the Arabian Shield. Dioritic plutons are concentrated in the southwestern part of the shield. $K_2O:K_2O+Na_2O$ values for each of the two magma series appear to increase to the northeast. The northeastward shift of the focus of intrusion from dioritic to granitic emplacement and the northeastward increase in potassium in both series are similar to trends in the Sierra Nevada batholiths of the western United States. By analogy with the Sierra Nevada, a continental-oceanic plate boundary may have existed to the southwest of the present Arabian Peninsula during the late Precambrian.

Lakathah layered titaniferous complex

Conrad Martin reports that the outer syenitic rim of the Lakathah layered complex of titaniferous rocks, previously thought to have been a separately emplaced ring dike, is now considered to be one of a number of phases of a gradational differentiated series. The other units include ferro-diorite, gabbro, and pyroxenite; they all include hornblende, pyroxene, apatite, and magnetite.

Gabbroic and associated syenitic rocks containing titaniferous magnetite are common in other parts of the Arabian Shield. These may well represent the differentiated calcic and alkalic phases, respectively, of a parental calc-alkalic sequence.

Tungsten and molybdenum anomalies at Al Kushaymiyah

Tungsten and molybdenum anomalies at Al Kushaymiyah, which were studied by P. K. Theobald and G. H. Allcott, are associated with the Uyaijah ring complex of silicic igneous rocks. Geologic mapping and sampling of surficial debris on a 1-km grid indicated two principal zones of mineralization, a central zone associated with quartz veins in quartz monzonite and a southern outer zone in tactite along a contact between quartz monzonite and metasedimentary rocks of the Murdama Group. Scheelite is the principal tungsten mineral and powellite is the principal molybdenum mineral: small amounts of molybdenite, pyrite, and chalcopyrite were noted in quartz veins that cut both mineralized zones. Aeromagnetic and gamma-ray spectrometric geophysical data contributed by G. E. Andreasen and V. J. Flanigan aided delineation of the major rock units.

Gamma-ray spectrometry aids geologic mapping on the Arabian Shield

V. J. Flanigan has analyzed airborne gamma-ray spectrometer data from three areas covering 8,500 km^2. Results indicate that the gamma-ray spectrometer is an effective geophysical tool for use as an aid to geologic mapping and mineral investigations on the Arabian Shield. Coupled with the study of the magnetic patterns, rock types associated with specific magnetic patterns and radiation levels can be suggested and their contacts inferred. Radiation and magnetic data correlate as well as complement each other. Intense magnetic patterns and low radiation intensity generally are reflected by rocks of mafic to ultramafic composition, whereas less intense magnetic patterns and radiation data of considerable variation are reflected by rocks of granitic composition. Source elements (potassium, thorium, and uranium) that contribute to total-count gamma-radiation anomalies are depicted on isoelement maps. Thus, the spectral data are valuable as an indirect means of mineral investigation; potassium enrichment or depletion is associated with some types of mineral deposits; thorium often is associated with concentrations of rare earths, and uranium can be used as a direct indicator of terrestrial concentrations of uranium minerals.

Magnetic data indicate evidence of sea-floor spreading in the Red Sea

G. E. Andreasen reports that analysis of magnetic data extending from Precambrian rocks on the Arabian Shield across the Red Sea axial trough indicates that the large-scale long-wave-length anomalies and trends are typical of anomalies associated with sea-floor spreading. The data suggest that sea-floor spreading is more extensive than thought by some investigators but less than proposed by others.

Tectonic map of Arabian Peninsula

The tectonic map is in final stages of preparation. G. F. Brown states that it attempts to evaluate structure and geologic history of some of the world's largest petroleum reserves. The concept of sea-floor spreading is applied to the Gulf of Aden and the Red Sea in the light of the geophysical measurements reported by numerous investigators. Not all the geological features can be explained by the concept, but the origin of the Gulf of Aden and the later Pliocene to Holocene events in the Red Sea are best explained by spreading. Most physical features and the distribution of ground water and oil deposits can be explained by movement in an older subduction zone involving the southern part of the Arabian Peninsula, followed by a younger subduction downwarping of the central part of the peninsula beneath the Persian (Arabian) Gulf. Several Precambrian orogenies have intensely deformed the rocks of the Arabian Shield. North-south structural features of the Hijaz orogeny are most predominant, and these are cut by northwest-southeast trends of the latest Precambrian-Cambrian Najd orogeny. Structural features older than the Hijaz orogeny, possibly related to the Kibaran orogeny of Africa, may be represented by old northeast-southwest trends.

Red Sea area

An investigation into the genesis and nature of the Red Sea "hot brines" was undertaken as a cooperative effort between WHOI and USGS under Saudi Arabian Government sponsorship. In March, WHOI vessel *Chain* left Massawa, Ethiopia, for Jidda, where P. D. Snavely, Jr., and D. R. Mabey of the USGS and Saudi Arabian officials embarked for a reconnaissance of the Red Sea coast northward from Jidda. This phase explored deeper Red Sea waters—more than 200 m—with seismic, gravimetric, and magnetic instruments. The course then veered southward into the Gulf of Aden. During the month-long cruise, much of it following a zigzag pattern across the median rift valley and eastern Red Sea shelf, bottom sediments were probed, their structure was studied, known hot-brine areas were investigated, and a search was conducted for new hot-brine areas. R. G. Coleman reports that volcanic fragments removed from core barrels taken in the hot-brine areas suggest

sediments resting on chilled basalt lavas rather than a sill-sediment relation. (For a discussion of Red Sea ores, see section on "Marine and Coastal Geology," p. A94.)

TURKEY

Mineral research and exploration

The Mineral Research and Exploration Institute of Turkey (MTA) and the USGS concluded a 4-yr mineral exploration and training project in Turkey. The main goals were to further the technical training and administrative skills of MTA. Laboratory, drilling, and printing equipment used to obtain the goals was provided as part of the project.

P. W. Richards reports that 18 men from the USGS spent a total of about 12 man-years on the project, and 13 men and women from MTA studied, under USAID's participant program, laboratory procedures, drilling techniques, cartography, printing methods, and field geology of mineralized areas in the United States. One participant worked with the U.S. Information Service in Beirut gaining experience in operation of a map press.

Four of eight subprojects combined geologic with geochemical or geophysical field studies in search for ore, mainly iron and base-metal deposits. The other four, in support of mineral exploration activities, included procurement of equipment and technical advice for the Analytical Laboratories, Technological (ore-dressing) Laboratories, diamond drilling, and geologic map publication.

Large areas in western and central Turkey were examined and covered by geologic, magnetic, and geochemical surveys. A low-grade magnetite deposit in the Hasan Çelebi area of central Turkey was drilled by MTA following the initial studies, and samples were analyzed in the ore-dressing and chemical laboratories. The analyses indicate that the magnetite is low in deleterious materials and can be readily separated and concentrated.

Copper anomalies near the Maden copper mine in the Ergani area of east-central Turkey were found by geologic mapping and geochemical surveys. They are being checked by geophysical (induced polarization) surveys and drilling.

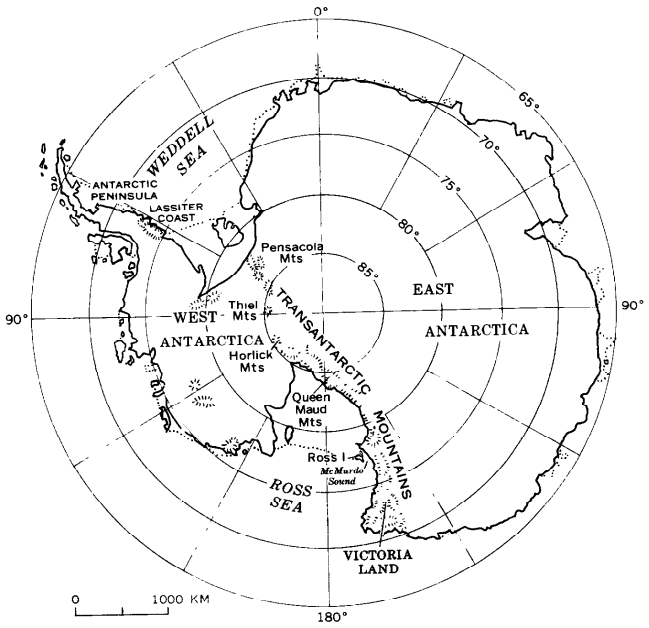
Other geochemical anomalies located in western Turkey have not yet been studied by MTA. Geologic and magnetic surveys in iron-bearing rocks of western Turkey indicated that some deposits may prove to be of commercial value, but most are too small to be of present economic interest.

Analytical equipment, chiefly an X-ray fluorescence spectrometer, a spectrograph, and two atomic-absorption spectrophotometers, was installed and calibrated in the Analytical Laboratories. The instruments are to be used for rapid analyses in support of mineral exploration projects and for basic research.

With assistance of a geologist and three specialists in cartography, photography, and printing, MTA initiated a new geologic publication program. New equipment and techniques enable MTA to produce geologic maps of excellent quality for all its publication series.

ANTARCTICA

Geologic field studies during the 1971-72 austral summer were carried out in the ice-free dry valleys of southern Victoria Land near McMurdo Sound (see index map) by personnel of the Branch of Astrogeologic Studies. These field activities, as well as laboratory studies in petrology, geophysics, geochemistry, and paleontology on Antarctic material collected during previous expeditions, are part of the U.S. Antarctic research program sponsored by the Office of Polar Programs of the U.S. National Science Foundation. The fieldwork is logistically supported by the U.S. Navy's Operation Deep Freeze. Progress in Antarctic aerial photography and topographic mapping, which are functions of the USGS Topographic Division, is reported in the section "Mapping in Antarctica" (p. A221).



Antarctic Martian analog studies

Martian analog geologic studies were carried out in the Taylor, Wright, and Victoria valleys near McMurdo Sound during December and January 1971-72 by H. E. Holt and E. C. Morris (USGS) and by T. A. Mutch (Brown Univ.). Of all possible terrestrial equivalents, the harsh surface environment of Antarctica is believed to be most like that of Mars because of its extreme coldness and aridity, its strong winds and saline surface waters, and its low biologic activity and virtual lack of fluvial processes. In addition to photographic documentation of weathering features, soils, patterned ground, desert pavement, desert varnish, and other evidence of eolian erosion and deposition, rock and soil samples were obtained for laboratory study; photometric, colorimetric, and polarimetric measure-

ments were made on selected rock and soil types. This information will provide an analog data bank for analysis of possible geologic units and small-scale surface features on photographs to be obtained from the Viking Lander Mission to Mars planned for 1975-76.

Late Precambrian volcanism in the Thiel Mountains

Textures and structures in partly recrystallized porphyritic-appearing silicic igneous rocks that are widespread in the Thiel Mountains, one of the southernmost ranges of the Transantarctic Mountains, are interpreted by A. B. Ford and C. T. Sumsion (1971) as being of pyroclastic origin. Modal and chemical analyses indicate that the rocks are quartz latites. The crystal-rich tuffs are characterized by an abundance of coarse broken plagioclase and embayed quartz crystals set in a variably recrystallized fine matrix of quartz and potassium feldspar, and by the general presence of minor primary cordierite and hypersthene and their alteration pseudomorphs. These and similar tuffaceous rocks in the Horlick and Queen Maud Mountains yield radiometric ages in the range of 600 to 700 m.y. Thus pyroclastic volcanism must have been widespread near the end of Precambrian time in the central Transantarctic Mountains. Calderas or other vents have nowhere been recognized and probably lie in nearby ice-covered terrain.

Copper mineralization in the Lassiter Coast area

Areas of copper mineralization in the nunataks of the western Rare Range, Lassiter Coast of the southeastern Antarctic Peninsula, were mapped in detail by P. D. Rowley, P. L. Williams, A. B. Ford, and R. L. Reynolds during the 1970-71 season. The nunatak area shows a complex history of intrusion, alteration, and mineralization, probably all of Cretaceous or possibly of early Tertiary age. Intrusion of a homogeneous granodiorite stock was followed by emplacement of even-textured to porphyritic zoned adamellite stock; both in turn were intruded by numerous northwest-trending dikes of porphyritic granodiorite and adamellite. Numerous steep northwest-striking shear zones, which cut all rocks, were the apparent source of pervasive hydrothermal solutions that resulted in alteration and copper mineralization apparently of the porphyry type. Although alteration extended for many tens of meters away from the shear zones, only minor visible copper sulfides were produced within the zones. Copper values rarely exceed 1,000 ppm; higher copper values are found only in scattered clots a few centimeters in diameter and in small quartz veins with massive chalcopyrite and molybdenite that occur in the more highly fractured rock of the oldest pluton. This finding of significant copper mineralization, the first to be mapped in detail in Antarctica, will hopefully encourage further study of copper blooms and sulfides that have been observed by numerous British scientists working in the northern part of the Antarctic Peninsula.

Mineralized preservation of Permian peat

Unusual examples of plant-tissue preservation in an Antarctic Permian peat deposit were found by J. M. Schopf (1971) in samples from Mount Augusta in the central Transantarctic Mountains. Very early chalcedonic mineralization must have occurred to account for preservation of these structures. Three different generations of silica and results of recrystallization and weathering suggest stages in geologic history of this ancient peat deposit, which elsewhere has been converted into coal.

Crustal structure of Pensacola Mountains area

Crustal thickness models computed by J. C. Behrendt, J. R. Henderson, L. J. Meister, and W. L. Rambo for the Pensacola Mountains area suggest an anomalously thin crust and a crust-mantle contact sloping approximately 45° across the transition from West to East Antarctica if a recently published deep seismic reflection, considered to have come from the crust-mantle interface, is used as control. If this interpretation is rejected and a normal crust is assumed, then a nearly vertical crust-mantle contact at the boundary between East and West Antarctica is required by the models, which is consistent with earlier published interpretations. In this normal crust the deep reflection must come from a discontinuity within the crust. The gravity data, supported by magnetic data, in either interpretation require a substantial section of low-density sedimentary rocks beneath the ice northwest of the Pensacola Mountains.

Area of ice-covered intrusion revealed by aeromagnetic data

Models fitted by J. C. Behrendt and others to the magnetic data across the Dufek layered mafic intrusion in the northern Pensacola Mountains are consistent with interpretation of a buried downfaulted block northwest of Dufek Massif. Magnetic and gravity data indicated a minimum area of the Dufek intrusion of 34,000 km^2, or at least half the size of the Bushveld complex. Two magnetic profiles across Berkner Island suggest that the intrusion could extend an additional 250 km north of the Dufek Massif, but this interpretation cannot be substantiated without additional data.

Density estimate of the Dufek intrusion

The stratiform Dufek intrusion is composed of a varied series of cumulate rocks ranging from predominantly pyroxene gabbro, some with abundant magnetite, to pyroxenite and anorthosite that are thinly interlayered within the gabbro. Stratigraphic variation of bulk-rock density is complex and unlike that of thin mafic sheets. Whereas in thin sheets density generally decreases gradually upward, in the Dufek body density trends show an overall upward increase which mainly reflects an upward increase in total iron in the mafic rocks.

Superimposed on this overall trend are numerous, large-scale increases and decreases in density which relate to thin interlayers of pyroxenite and anorthosite. Density, except for magnetite-rich rocks, shows a close linear relationship to color index.

The Dufek body obviously must be considered as an inhomogenous mass, with significant density variants, for highly accurate gravity interpretations. Although densities range from as low as 2.65 g/cm^3 for granophyre and 2.70 for anorthosite to about 3.30 for pyroxenite, such extreme values for thin layers must be averaged with adjoining layers in considering effects on surface gravity. Preliminary calculations by A. B. Ford, using values weighted according to thicknesses of layers represented by measured samples, indicate that density of the lower 2 km of section (Dufek Massif) averages about 2.95 g/cm^3 and of the upper 2 km exposed (Forrestal Range) averages about 3.03 g/cm^3. These values together with estimates for unexposed sections suggest that the average density for the entire complex approximates that of average norite, about 2.98 g/cm^3.

TOPOGRAPHIC SURVEYS AND MAPPING

OBJECTIVES OF THE NATIONAL TOPOGRAPHIC PROGRAM

A major function of the U.S. Geological Survey is to prepare and maintain maps of the National Topographic Map Series, covering the United States and its outlying areas. The several series, at various scales, constitute a fundamental part of the basic data needed to inventory, develop, and manage the natural resources of the country. Other mapping functions of the Geological Survey include the production of special maps and research and development in mapping techniques and instrumentation.

Procedures for obtaining copies of the map products are given under "How to Obtain Publications" in the section "U.S. Geological Survey Publications" (p. A232–A233).

FEDERAL MAPPING COORDINATION

Since 1967, when responsibility for governmentwide coordination of federally funded domestic surveying and mapping activities was given to the Department of the Interior (and subsequently to the USGS) by the Office of Management and Budget, significant progress has been made toward achieving more effective coordination. Channels of communication have been established with other agencies, and surveying and mapping needs, products, programs, and capabilities have been identified.

The USGS recommended revision of Office of Management and Budget Circular A-16 (and related exhibits) and broadened coordination to include mapping beyond that which contributes to the current National Topographic Program.

The USGS is gathering data to be used for evaluating the need for a national large-scale urban mapping program.

At the request of the Bureau of the Census, the USGS tested the horizontal accuracy of a random sample of the Census metropolitan area series of 1:24,000-scale maps.

Meetings were held with Federal Highway Administration and State highway department representatives to discuss State mapping programs and needs and to coordinate revision programs to prevent duplication of mapping.

The USGS hosted a technical exchange conference for other Federal agencies involved in mapping, charting, and geodetic activities.

MAPPING ACCOMPLISHMENTS

Quadrangle map coverage of the Nation

General-purpose topographic quadrangle map coverage at scales of 1:24,000, 1:62,500, 1:63,360 (Alaska), and 1:20,000 (Puerto Rico) is now available for about 87 percent of the total area of the 50 States, Puerto Rico, the Virgin Islands of the United States, Guam, and American Samoa. Included in this coverage is about 7 percent of the total area which is not yet published but which is available as advance manuscript

During fiscal year 1972, 1,990 maps were published covering previously unmapped areas equivalent to about 3.2 percent of the area of the 50 States and territories referred to above. In addition, 531 new maps at a scale of 1:24,000, equivalent to about 0.9 percent of the total area, were published to replace 15-minute quadrangle maps (1:62,500 scale) which did not meet present needs. Figure 7 shows the extent and location of the current topographic map coverage.

Map revision and maintenance

As maps become out of date, revision is necessary to show changes in the terrain and changes and additions to manmade features such as roads, buildings, and reservoirs. During fiscal year 1972, 960 general-purpose quadrangle maps of the 7½-minute series (1:24,000 scale) were revised. Most of these revised maps are in expanding urban areas or in States that are completely mapped in the 7½-minute series. About 80 percent of the 2,400 maps currently in the revision program (fig. 8) are being updated by photorevision (interim revision), a low-cost rapid-production method that relies primarily on photointerpretation. Recent aerial photographs of the areas to be revised are inspected, and changes in cultural and planimetric features are noted and printed in purple on the revised map. Manuscript prints showing the information used in first, second, and subsequent revisions are available to map users who need the progressive information.

About 20 percent of the maps in the revision program are revised by photogrammetric, field, and cartographic operations (standard or complete revision).

In fiscal year 1972, about 1,000 general-purpose quadrangle maps were reprinted to replenish stock.

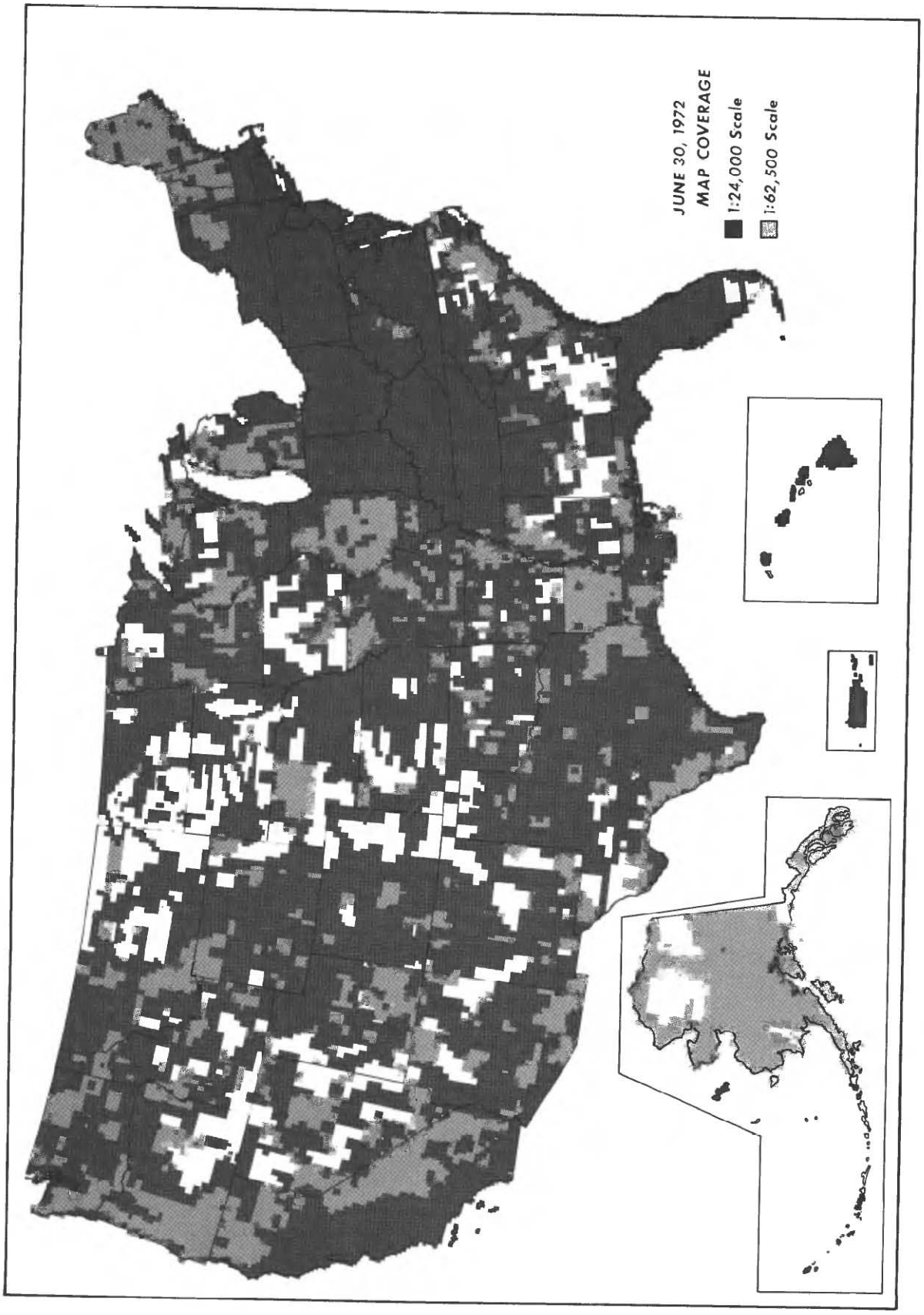


Figure 7.—Status of 1:24,000- and 1:62,500-scale mapping of the 50 States and Puerto Rico.

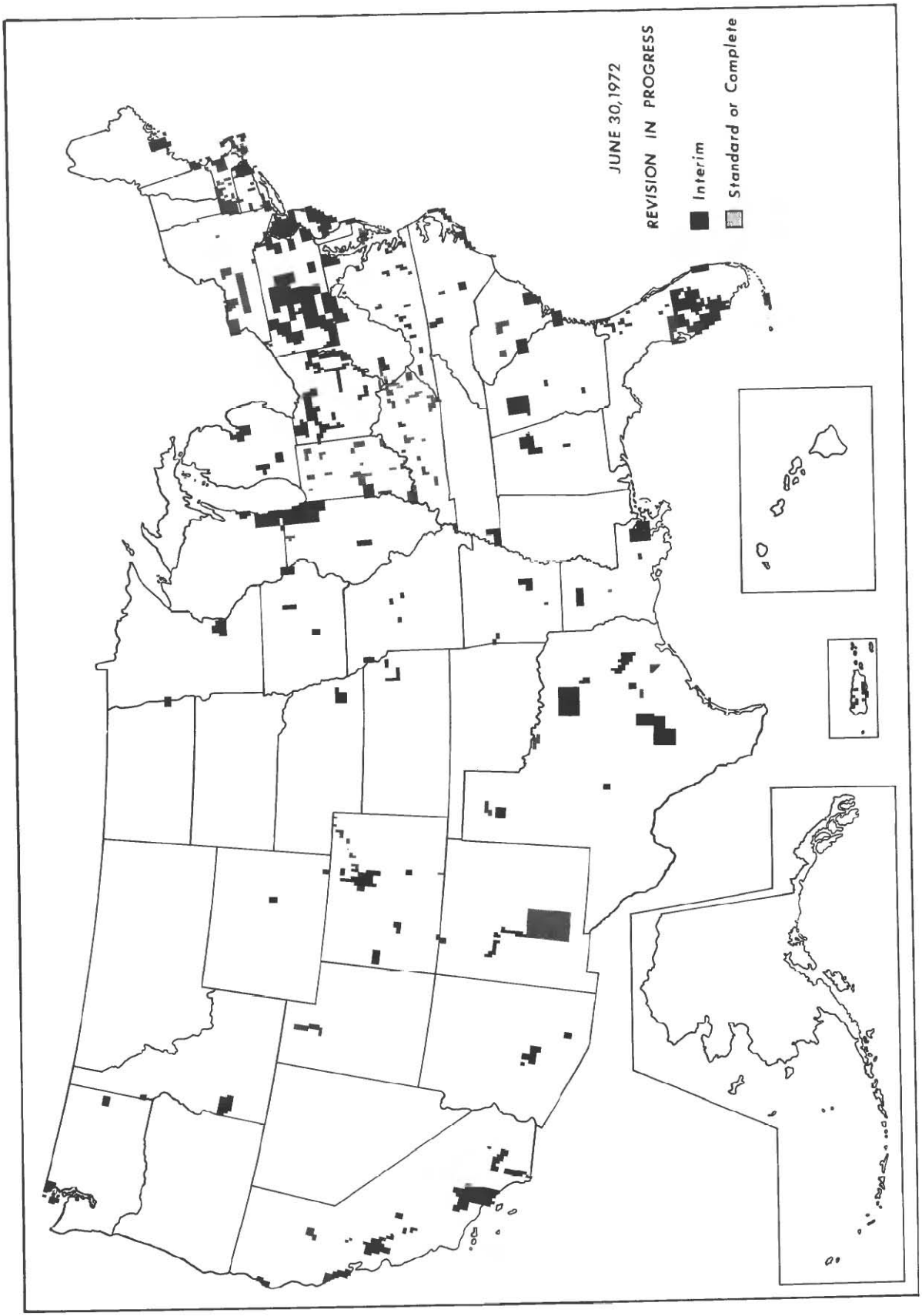


Figure 8.—Revision in progress, 1:24,000-scale topographic maps of the 50 States and Puerto Rico.

1:250,000-scale series

The 48 conterminous States and Hawaii are completely covered by 1:250,000-scale maps originally prepared as military editions by the U.S. Army Map Service (now Topographic Center, Defense Mapping Agency). These maps are revised and maintained by the USGS with certain changes and additions to make them more suitable for civil use. The USGS is replacing its Alaska Reconnaissance Series Maps at 1:250,000 scale with an improved series based on larger scale source material and on new photogrammetric compilations. Figure 9 shows revision in progress on 1:250,000-scale maps.

State maps

State maps are published at scales of 1:500,000 and 1:1,000,000 for all States except Alaska. State maps of Alaska are published at scales of 1:1,584,000, 1:2,500,000, 1:5,000,000, and 1:12,000,000. The series of State maps compiled according to modern standards now includes 46 maps covering 50 States and the District of Columbia (fig. 10). All these maps are published in planimetric editions; contour and shaded-relief editions are also available for most of them. Sixteen of the maps—Alaska, Arizona, Illinois, Kentucky, Maine, Maryland-Delaware, Massachusetts-Rhode Island-Connecticut, New Hampshire-Vermont, New Jersey, New York, North Carolina, Ohio, Pennsylvania, Tennessee, Utah, and Virginia—are being revised, and new topographic maps are being prepared for Indiana, Mississippi, and Oklahoma. Other States are covered by an earlier series, also shown in figure 10.

National-park maps

Maps of 43 of the 214 national parks, monuments, historic sites, and other areas administered by the National Park Service have been published. These usually are made by combining the existing quadrangle maps of the area into one map sheet, but occasionally surveys are made covering only the park area. Most of the other parks, monuments, and historic sites are shown on maps in the general-purpose

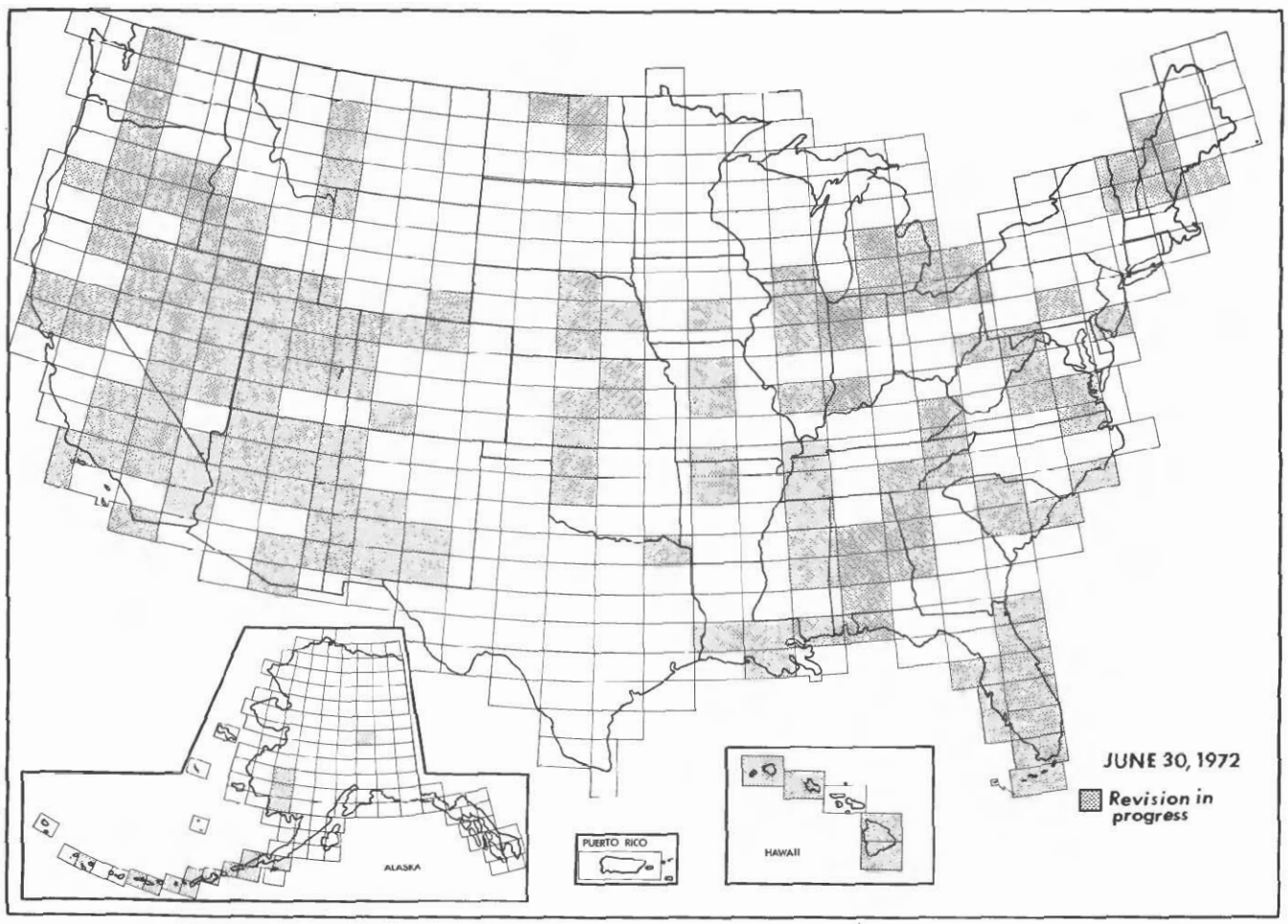


Figure 9.—Revision of 1:250,000-scale topographic maps.

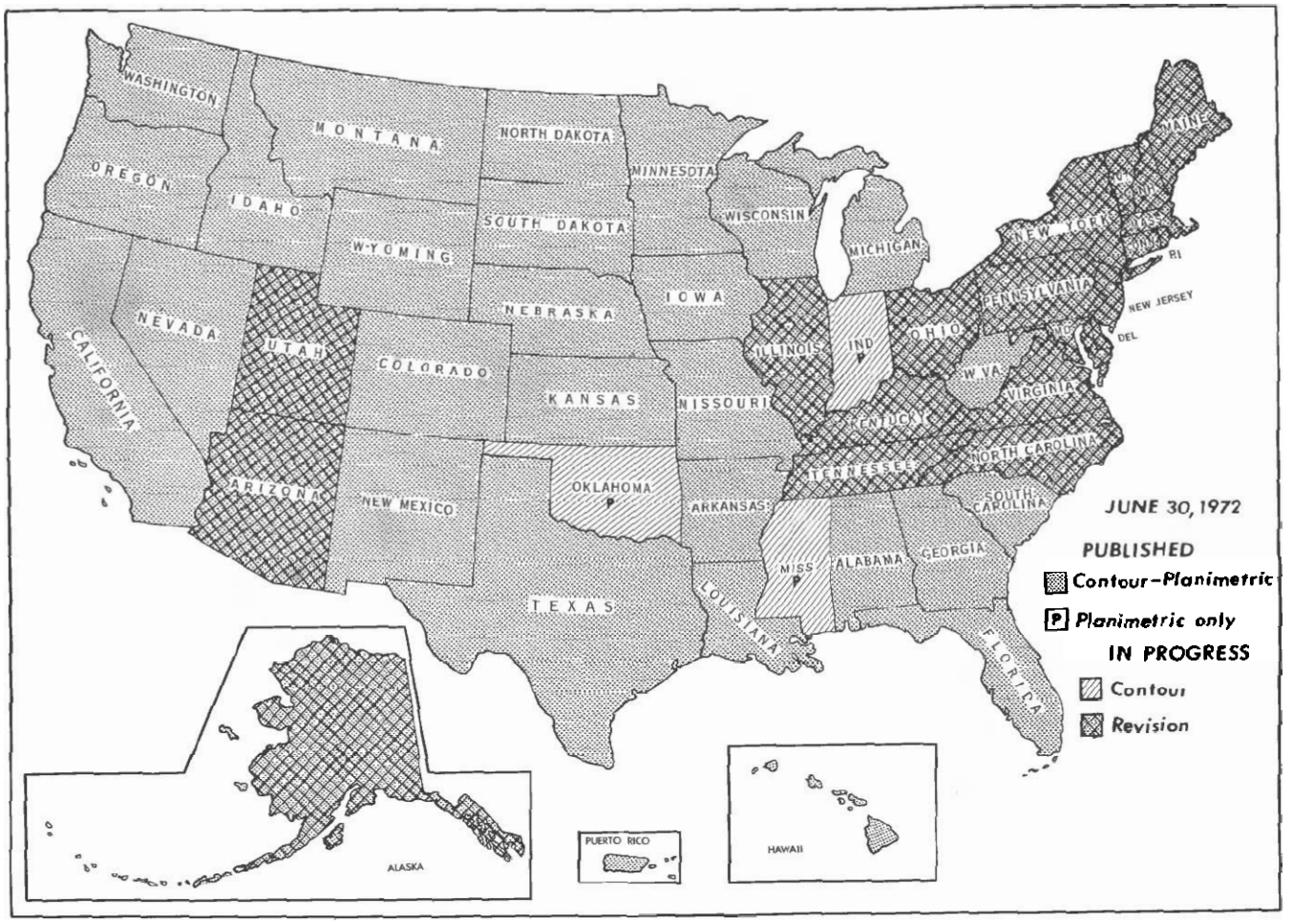


Figure 10.–Status of State maps

quadrangle series. Published maps in the national-park series include:

Acadia National Park, Maine
Badlands National Monument, S. Dak.
Bandelier National Monument, N. Mex.
Black Canyon of the Gunnison National Monument, Colo.
Bryce Canyon National Park, Utah
Canyon de Chelly National Monument, Ariz.
Canyonlands National Park, Utah
Carlsbad Caverns National Park, N. Mex.
Cedar Breaks National Monument, Utah
National Monument, Utah
Colonial National Monument (Yorktown Battlefield), Va.
Colorado National Monument, Colo.
Crater Lake National Park, Oreg.
Craters of the Moon National Monument, Idaho
Custer Battlefield, Mont.
Devils Tower National Monument, Wyo.
Dinosaur National Monument, Colo.-Utah
Franklin D. Roosevelt National Historic Site, N.Y.
Glacier National Park, Mont.
Glen Canyon National Recreation Area, Utah-Ariz.
Grand Canyon National Monument, Ariz.
Grand Canyon National Park, Ariz.
Grand Teton National Park, Wyo.
Great Sand Dunes National Monument, Colo.
Great Smoky Mountains National Park, N.C.-Tenn. (2 sheets)
Greak Smoky Mountains National Park and vicinity, N.C.-Tenn.
Isle Royale National Park, Mich.
Lassen Volcanic National Park, Calif.
Mammoth Cave National Park, Ky.
Mesa Verde National Park, Colo.
Mount McKinley National Park, Alaska
Mount Rainier National Park, Wash.
Olympic National Park, Wash.
Petrified Forest National Park, Ariz.
Rocky Mountain National Park, Colo.
Scotts Bluff National Monument, Nebr.
Sequoia and Kings Canyon National Parks, Calif.
Shenandoah National Park, Va. (2 sheets)
Vanderbilt Mansion National Historic Site, N.Y.
Vicksburg National Military Park, Miss.
Wind Cave National Park, S. Dak.
Yellowstone National Park, Wyo.-Mont.-Idaho
Yosemite National Park, Calif.
Yosemite Valley, Calif.
Zion National Park (Kolob section), Utah
Zion National Park (Zion Canyon section), Utah

Maps of the Glacier, Grand Canyon, Great Smoky Mountains, Mammoth Cave, Mesa Verde, Mount McKinley, North Cascades, and Yosemite National Parks; Point Reyes National Seashore; and Death Valley and Great Sand Dunes National Monuments are being compiled or revised.

Million-scale maps

The worldwide million-scale series of topographic quadrangle maps was originally sponsored by the International Geographical Union and designated the International Map of the World on the Millionth Scale (IMW). Twenty-five of 53 maps required to cover the conterminous United States have been published.

From 1955 to 1959, the U.S. Army Map Service (now Topographic Center, Defense Mapping Agency) published 27 maps of the conterminous United States and 13 maps of Alaska in a military series at the scale of 1:1,000,000. Although these maps do not meet the IMW specifications in all respects, they are recognized by the United Nations Cartographic Office as provisional editions in the IMW series (fig. 11).

Two of the maps, Hudson River and San Francisco Bay, are no longer available as IMW maps, but the areas are covered by maps in the military series. Maps of both the IMW and the military series are available for Boston, Chesapeake Bay, Hatteras, Mississippi Delta, Mount Shasta, and Point Conception. In addition, the American Geographical Society published the Sonora, Chihuahua, and Monterrey maps; and Canada published the Kootenay Lake, Lake of the Woods, Ottawa, Regina, Vancouver, and Winnipeg maps. Puerto Rico is covered by two maps compiled by the American Geographical Society and published by both the Society and the Defense Mapping Agency. Work in progress includes seven new maps and three maps being revised: Andreanof Islands, Attu Island, Blue Ridge, Chicago, Cold Bay, Des Moines, Hawaii, Hudson River, Lake Erie, and Ozark Mountains.

Orthophotomapping

Orthophotomaps have been established as the standard 1:24,000-scale publication for many areas where conventional

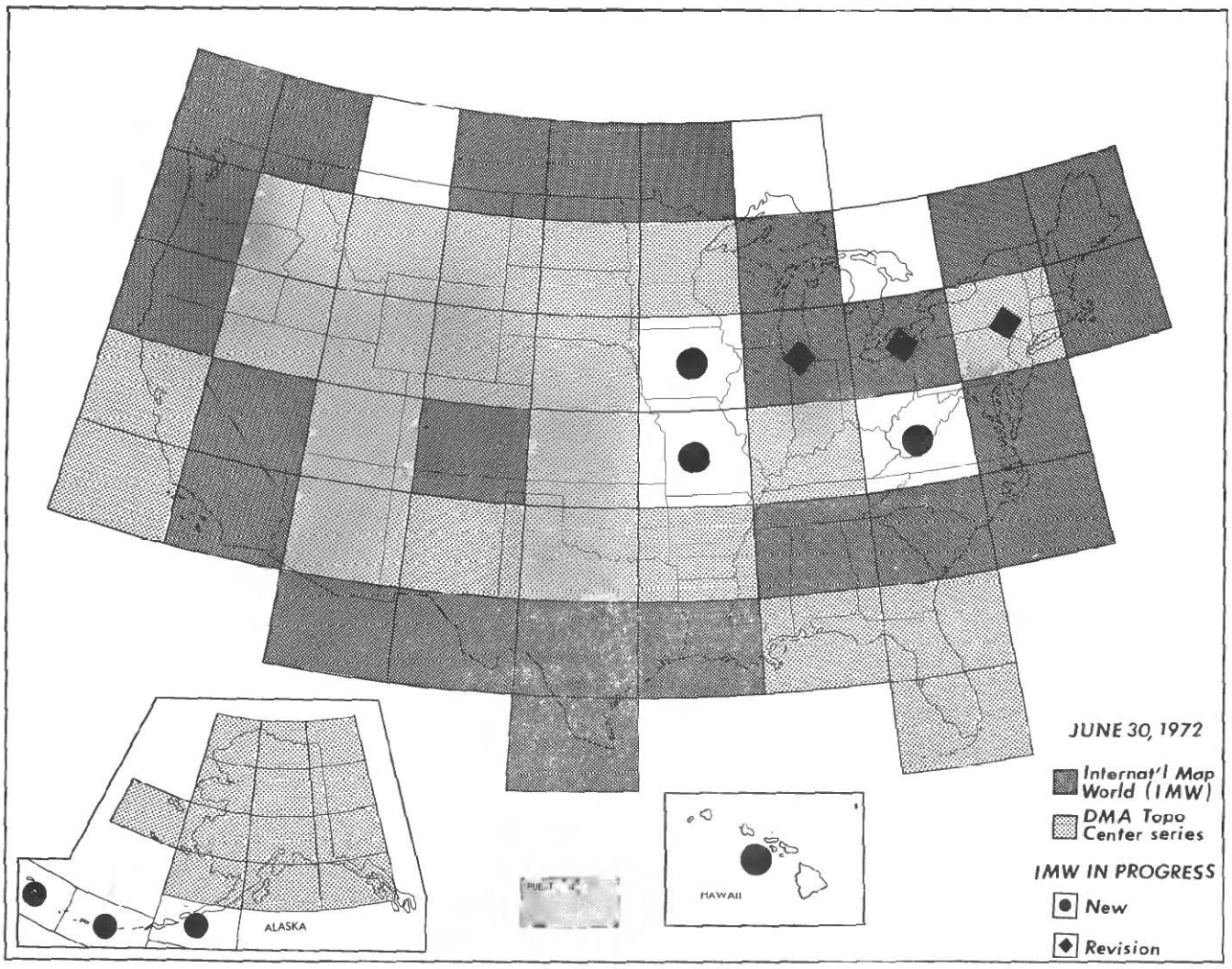


Figure 11.—Status of publication of 1:1,000,000-scale topographic maps. Work in progress is being done by the USGS.

cartographic symbolization cannot adequately portray existing detail. Orthophotomapping is particularly effective for swamps, deserts, coastal plains, and other areas of low relief. About 50 standard orthophotomaps have been published at 1:24,000 scale with 475 additional quadrangles in the current orthophotomapping program.

Orthophotoquads, which are orthophotomosaics or orthophotographs in map format with limited cartographic treatment, are being prepared as an interim product in many areas.

MAPPING IN ANTARCTICA

The USGS continued to assist the National Science Foundation in its U.S. Antarctic Research Program (USARP) by assigning four field engineers for the 1971–72 austral field season. Their primary projects were (1) to establish control over a 2,300-sq-mi area in the Transantarctic Mountains of southern Victoria Land for aerophotogrammetric compilation of eight orthophotomaps at 1:50,000 scale, and (2) to conduct a Doppler translocation experiment to determine the feasibility of using the Navy Navigational Satellite System (NAVSAT) for establishing mapping control, studying ice movement, and positioning return-beam vidicon imagery that will be obtained under the ERTS-A and B program.

Topographic field operations

E. E. McClelland, C. E. Morrison, G. W. Nottage, and L. L. Sanford completed approximately 600 mi of traverse using electronic distance-measuring instruments and established 89 control points for the dry valleys orthophotomapping project. Operating in two teams, the engineers conducted the Doppler translocation experiment. They were assisted by C. L. Baumann (Johns Hopkins Univ., Appl. Physics Lab.) in installing, operating, and maintaining two U.S. Navy Doppler receivers. Data from 1,600 satellite passes are being analyzed by the Applied Physics Laboratory.

Other projects completed by the engineers included establishing a tide-gage bench mark at McMurdo Station, making a geodetic tie to the University of Texas Geodetic Satellite Observatory, and establishing eight vertical bench marks at specified locations in the Victoria, Wright, and Taylor dry valleys at the request of Dr. D. L. McGinnis, Northern Illinois University, for subsequent use by an international program, the Dry Valley Drilling Project.

Aerial photography

No new aerial photographs were obtained for the 1:250,000-scale reconnaissance topographic mapping program; however, false color (infrared) mapping photographs were taken over the dry valleys area for the 1:50,000-scale orthophotomapping program. Tricamera reconnaissance-quality photographs were obtained for magnetometer and radio-sounding ice-thickness surveys. Panchromatic photographs for science programs were taken over the Cape Hallett Rookery and in the Amundsen and Bellinghausen Seas for penguin and seal population studies. Vertical panchromatic infrared and infrared color photographs were taken over the Meserve, Hart, Bartley, and Goodspeed Glaciers of southern Victoria Land for glaciological studies. Block vertical panchromatic coverage at 1:50,000 scale was obtained of the eastern slope of the Royal Society Range for the U.S.S.R. exchange scientist.

Cartographic activities

The status of USGS topographic mapping in Antarctica is shown in figure 12. Three 1:250,000-scale maps (Guest Peninsula, Alexandra Mountains, and Boyd Glacier) covering 24,500 sq mi of the Saunders Coast area of Marie Byrd Land were made ready for printing. New mapping projects include two 1:1,000,000-scale maps (McMurdo Sound region, Ross Ice Shelf) and standard revision of the Ross Island 1:250,000-scale map. Production is underway on 18 topographic maps at 1:250,000 scale, covering 89,000 sq mi east of Saunders Coast, and on one 1:500,000-scale sketch map covering about 56,000 sq mi of Palmer Land. Aerial photography and ground control are available for 13 additional maps at 1:250,000 scale covering about 65,000 sq mi of Ellsworth Land.

NATIONAL ATLAS

The National Atlas of the United States of America was published early in 1971. The Atlas was compiled as a reference tool of high quality for use by public officials, business and industrial organizations, libraries, educational institutions, and scholars throughout the world who seek information about the United States. The 431-page volume required 8 years of work and involved the cooperation of more than 80 Federal agencies and numerous commercial firms, specialists, and consultants. It contains 336 pages of multicolored maps and an index with more than 41,000 entries. The following individual map sheets are available as separate sales items:

- United States general reference
- Physiography and physiographic divisions
- Land-surface form
- Classes of land-surface form
- Tectonic features (Alaska)
- Tectonic features (conterminous United States)
- Geology
- Monthly average temperature
- Monthly minimum temperature
- Surface water
- Principal uses of water
- Territorial growth
- Major forest types
- Distribution of principal kinds of soils: orders, suborders, and great groups
- Potential natural vegetation of Alaska and Hawaii
- Potential natural vegetation (conterminous United States)
- Monthly sunshine
- Annual sunshine, evaporation and solar radiation
- Population distribution, urban and rural: 1960
- Federal lands
- Population trends
- Congressional districts for the 91st Congress
- Shaded relief (conterminous United States)
- Shaded relief (Alaska).

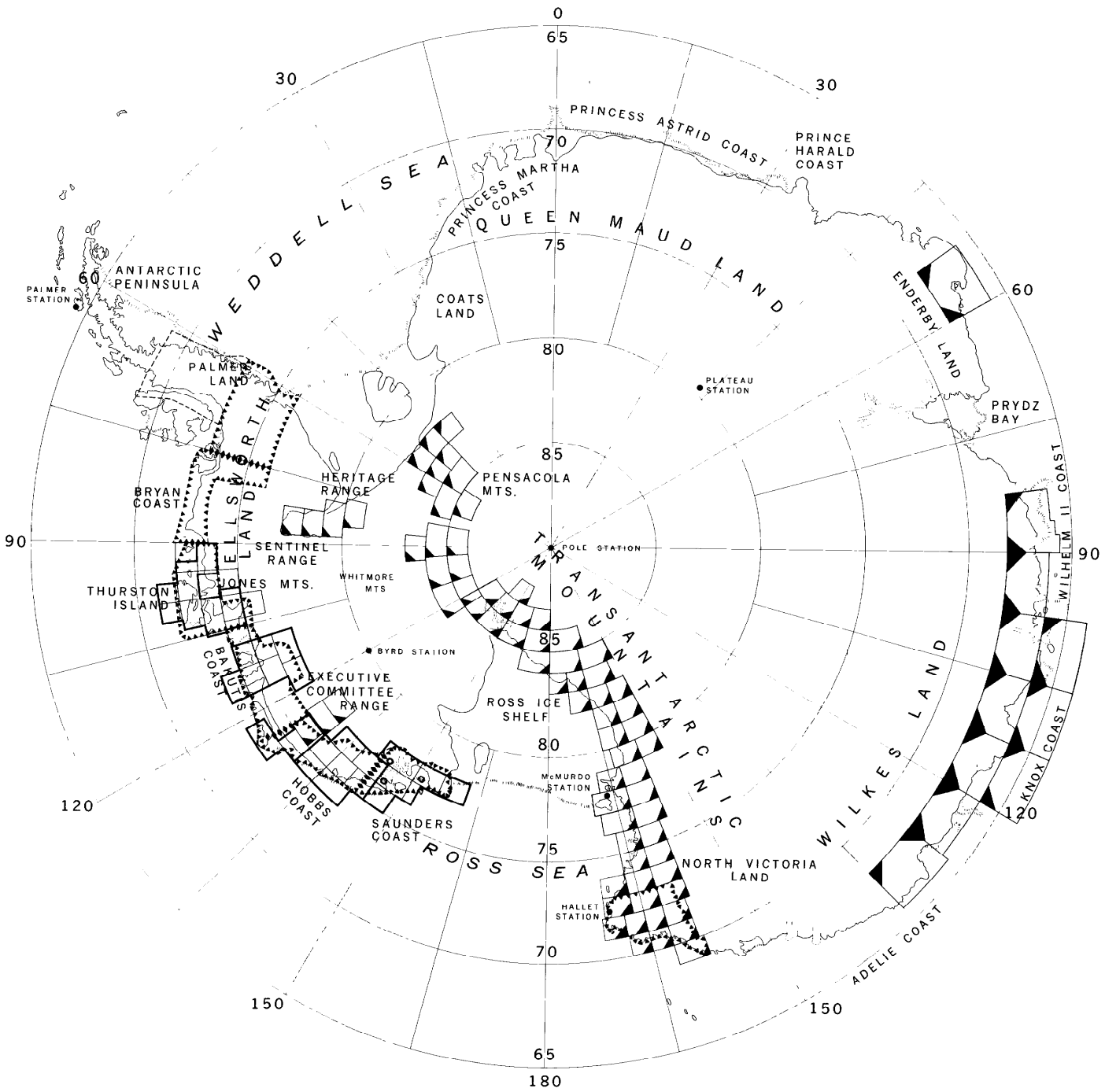


Figure 12.–Index map of Antarctica, showing status of topographic mapping.

INTERNATIONAL ASSISTANCE PROGRAMS

Brazil

M. L. McKenzie, photogrammetric specialist, attended the Fifth Brazilian Congress on Cartography, lectured at the University of Guanabara, and visited private and governmental mapping agencies during July and August 1971 to discuss problems in photogrammetric aerotriangulation.

Liberia

The geological exploration and resources appraisal project in Liberia is a cooperative effort of the Government of Liberia and the USGS under the sponsorship of the USAID. Cartographic work continued on the 1:250,000-scale geographic shaded-relief maps of Liberia and will be completed in 1972. The Survey assigned one cartographer to this project.

Mexico

A memorandum of understanding was concluded in January 1972 between the Comisión de Estudios del Territorio Nacional (CETENAL) of Mexico and the USGS. This memorandum constitutes an agreement between the two agencies regarding mapping and exchange of information along the Mexican-United States border.

Saudi Arabia

The USGS is continuing to assist the Ministry of Petroleum and Mineral Resources of the Kingdom of Saudi Arabia in assessing the mineral potential of the Precambrian shield area of central and western Saudi Arabia. The USGS assigned a photogrammetric specialist and an engineer geodetic specialist in support of the mineral investigations program. Maps of several areas of geologic interest have been compiled photogrammetrically by personnel in the United States as base maps for geologic reports.

Pan American Institute of Geography and History (PAIGH)

The USGS provided administrative and staff support for the United States member of the Commission on Cartography and for the chairman of the Committee on Topographic Maps and Acrophotogrammetry. Eight USGS personnel are actively participating in PAIGH activities. A report prepared by David Landen on "New Developments in Photogrammetric Techniques in the Americas" is being translated into Spanish for publication and distribution in Latin America.

Training programs and inquiries

Training in mapping operations was provided for participants from Afghanistan, India, Mexico, and Vietnam. The participants were sponsored by the United Nations, USAID, or special fellowship funds. Academic programs were arranged at selected universities in the United States for some of the participants. Technical reports and publications, information on sources of equipment, instructions on new mapping techniques, and proposed solutions of mapping problems were provided to foreign countries in response to many requests.

RESEARCH AND DEVELOPMENT

FIELD SURVEYS

Equipment developments

Desk calculators were used extensively for geodetic computations during the past year. What could be considered a revolution in programable desk calculators occurred, and new models and makes appeared almost monthly. Generally, designers developed greater capacity without increasing size or weight and greater diversity through plug-in function circuits and peripheral devices such as typewriters, x–y plotters, and digitizers. An optimum combination to suit any particular computing requirement could be found. Except for large net adjustments, all geodetic survey problems can be computed on these machines. They could be shipped to field offices and used for immediate check of fieldnotes, which, in many situations, could save considerable time and expense.

The USGS started in 1964 using coppercoated steel rods to support bench mark tablets. Each year further developments were made in techniques of driving, coupling, and surface monumenting of these types of control marks. Last year, a double-burner propane torch was designed and built for use in soldering couplings and bench-mark tablets to the copper-coated steel rods. The torch simultaneously heats both sides of the joint and thus speeds up the work, especially on windy days.

A gradual conversion of geodetic leveling to the metric system was followed by replacing old yard rods with new metric rods. During the past year, 14 pairs of metric rods were purchased, which brought the Topographic Division total to 18. On the new rods the graduations were engraved at 1-cm intervals on a nickel-iron alloy strip suspended in an aluminum alloy frame. Each rod was completely calibrated before field use. Six additional pairs were scheduled for purchase during the coming year.

Representatives of six major government surveying and mapping agencies participated in a cooperative test of a prototype electronic distance measuring (EDM) instrument designed by the Tellurometer Division of Plessey Electronics Corp. It is the smallest self-contained EDM instrument available to date, with weight, including battery, only 8 pounds approximately. Accuracy was within the manufacturer's specifications of ±15 mm (0.05 ft). Maximum range

was about 30 km (100,000 ft). The laser is used in a new type of EDM instrument, the Laser Ranger, which was also tested. Computing circuits display the slope distance instantly on the rear panel. Corrections are present for instrument and reflector constants, temperature, and pressure. Arrangements were made with the Army Mobility Research and Development Center, Fort Belvoir, Va., for the loan of an instrument, which was to be tested by each of the field offices. First reports were highly favorable for measurements of distances up to about 6 km.

Doppler positioning system

A coordinated series of tests of Doppler positioning was made by the USGS in Antarctica during the austral field season of 1971–72. With technical support provided by the Applied Physics Laboratory, John Hopkins University, USGS engineers tested two modes, the single-point or navigational method and the translocation method.

Three ranges of translocation were tested (40 km, 600 km, and 1,300 km) by measuring the three-dimensional position differences for each side of small, medium, and large triangles. The site at McMurdo Station was common to all three triangles. Other sites were at White Island, Brown Peninsula, Hallett Station, Brockton Weather Station, Byrd Station, and the Pole Station. For each triangle side, satellite-tracking data were recorded simultaneously at each end for 3 days (more than 75 passes). The data, including 2-minute Doppler counts and the satellite ephemeris, were printed out and also punched on paper tape. The smallest triangle was also surveyed by conventional instruments (Electrotapes and Wild T-2 theodolites) to provide a standard for calibrating the Doppler system. The tests provided valuable experience with all instruments in the Doppler system. Only preliminary results are available. The positions determined by 16 passes for the stations of the small (40-km) triangle gave distances that differed from the surveyed distances by 6, 10, and 11 m. The same 16 passes in the translocation mode gave distance errors of 3, 1, and 3 m. Results are expected to improve when all the data have been processed.

PHOTOGRAMMETRY

Imaging characteristics of photogrammetric camera systems

For 2 years, research has progressed in exploring the practical application of the latest image-quality evaluation techniques to the analysis of aerial camera systems used for photogrammetric mapping. Specially designed target arrays were photographed in the laboratory and in the air with Wild RC-8 and Zeiss RMK-A 30/23 cameras on several Kodak aerial films. The photographs were analyzed in terms of response functions, resolving power, graininess, and detectability and measurability of small image detail. The effects of relevant parameters, such as lens distortion, lens aperture, shutter function, image motion, film type, and target contrast, were determined. The methods devised for assessing individual effects were integrated into computer programs and related procedures for analyzing image quality and predicting and comparing performance. Values of the various evaluation factors were influenced to some degree by test conditions or other parameters and were not always equal for any particular camera system. Biases and trends emphasize the need for including all evaluation factors in judging the imaging characteristics of camera systems or the image quality of aerial photographs. Reasonable agreement was found between predicted and actual response functions for the various camera systems tested. The results demonstrate the validity of the technique of cascading response functions to predict operational performance on the basis of laboratory performance. The Wild and Zeiss cameras had essentially equal resolving power on the same kind of film exposed. On the basis of the project findings and conclusions, it was recommended that the methodologies developed in the research be applied in USGS operations requiring evaluation of photoimage quality or analysis of camera system capabilities.

BAI image correlation system

The BAI Corp.'s SG-3 image correlation system is now in the final stages of instrument testing. Developed for use in analytical photogrammetry, the BAI system has the unique capability of (1) recording and storing an unlimited number of signatures that define image points and (2) correlating signatures of corresponding points appearing on overlapping or time-variant photographs or on imagery in other bands of the electromagnetic spectrum. A comparator with a readout device measures and records the precise positions of the points.

Optimum values were established for most operating parameters of the system, such as camera aperture, scan radii, annulus width, and scaler range. Instrumental preferences for type and character of image points were determined. A test was planned for analytical aerotriangulation block adjustment of point-transfer data to provide a practical measure of the BAI system.

Photogrammetric map evaluation

The requirement that USGS maps meet National Map Accuracy Standards necessitates the annual checking of a percentage of new maps by field methods. A project was designed to provide data on which to base a photogrammetric evaluation of the horizontal accuracy of 32 early vintage 7½-minute maps. Horizontal data were obtained by fully analytical aerotriangulation of super-wide-angle photographs taken in the spring of 1971 at a flight height of 20,000 ft. National Geodetic Survey (NGS) triangulation monuments, at a spacing of approximately 15 minutes, were targeted in advance of photography for horizontal control.

Twelve maps were found to have unacceptable graticules, and inaccuracies in the graticules affected the test results for the planimetry. New graticules will be plotted for these maps and reconciled with map detail in a best-fit solution. Only the maps with acceptable graticules were evaluated by a least-squares fit to the graticules. However, the relative accuracy of all 32 maps was evaluated by a least-squares fit of map coordinates of test points to aerotriangulated coordinates. On this basis, only six of the 32 quadrangles have unacceptable horizontal accuracy, provided that new bases are plotted to replace the 12 unacceptable graticules.

In an extension of the research, work is underway to determine whether semianalytical or fully analytical aerotriangulation is more practical for photogrammetric evaluation of maps. Data will be obtained by semianalytical aerotriangulation of a part of the project and compared with those obtained by fully analytical aerotriangulation.

Compilation

Obvious savings would be realized through the use of high-altitude photographs for compilation. A research project was started to explore the practicality of compiling 1:24,000-scale standard line maps from 1:70,000-scale photographs. The aerial photographs were taken at 35,000 ft with Kodak Aero-Neg color film in a Zeiss 6-in. camera over a mapping project near Gillette, Wyo. To provide maximum-quality imagery for the compiler, the film was processed by Eastman Kodak Laboratories to positive film transparencies, which were then used directly in a Kern PG-2 stereoplotter specially modified to provide up to × 16 viewing magnification. The project was designed to compare planimetry against field-checked positions and contours against withheld field elevations. Preliminary observations in two stereomodels indicated that the trial will be successful.

Aerotriangulation

The direct geodetic constraint method of fully analytical aerotriangulation was programed for the IBM 1130 with 8-k word memory. The program provides the capability of a simultaneous solution for units of up to five photographs within core and for blocks of up to 25 photographs with disk storage.

The Louisburg, N.C., research project was designed to develop and test ways of increasing the productivity of fully analytical aerotriangulation. The project involves the use of super-wide-angle photographs taken at higher-than-normal flight height—22,000 ft—to establish supplemental horizontal and vertical control for wide-angle compilation photographs flown at 9,200-ft flight height. About 90 vertical and 12 horizontal control points were targeted in the field before photography. Preliminary testing was started to evaluate the accuracy of the method. Super-wide-angle photographs were taken at 11,000 ft for routine project aerotriangulation if the test does not prove successful.

Aerial photography

A booklet "Standard Specifications for Aerial Photography for Photogrammetric Mapping" was revised and published. This document provides standards for quality control of aerial photography, obtained almost exclusively by contracts with private firms, for mapping operations of the USGS. The new specifications differentiate between aerial photography for standard compilation, for fully analytical aerotriangulation, and for orthophotography. Additional changes regarding cameras, delivery schedules, and types of materials simplify the preparation and interpretation of the bidding schedule in the procurement process.

A total of 147,000 sq mi of aerial photography at a cost of $525,000 was obtained in the past year. Routine 6-in. photography again dominated the program. However, use of super-wide-angle photography increased to about 20 percent of the total. High-altitude (38,000 ft and up), 6-in. photography continued in demand. Preselection of an exposure station over each quadrangle center permits full coverage of a standard 7½-minute quadrangle with a single photograph. This practice eliminates mosaicking of orthophotographs to form each 7½-minute quadrangle and therefore improves the image quality and accuracy of an orthophotoquad.

During the year, Federal Aviation Administration (FAA) lowered the minimum altitude of the Positive Control Airspace (PCA) to 18,000 ft nationwide, an action intended to safeguard airline cargo and passenger carriers. Because of the likely effect of the FAA regulation on the entire aerophotogrammetric field, the American Society of Photogrammetry (ASP) with USGS support undertook discussions with FAA on the subject. Cooperating with ASP, FAA issued a memorandum to all its field personnel about the activities and requirements of a photographic mission. Further meetings will discuss future actions needed; audiovisual training aids may be made available to FAA for an air-traffic-controller training program.

CARTOGRAPHY

Slope mapping

Maps that show areas of critical ranges of slope are extremely useful in studies of geology, soil mechanics, drainage, urban planning, industrial development, and various other subjects related to land use. The USGS continued developing photomechanical techniques in which contour lines are widened by predetermined amounts so that contours touching each other indicate specific slope zones. In a series of line-weight-reduction and masking steps, these areas are permanently recorded on film in a format suitable for reproduction.

The lines are spread by exposing, with a controlled light

source, a sandwich consisting of a negative copy of the contours, a transparent spacer, and unexposed film. Either a fixed light source or a revolving illuminator can be used, but with each kind of light the exposure time and spacer thickness must be predetermined to provide the required line-weight control and repeatability.

A four-zone slope map was recently completed as part of a cooperative research project with the Atomic Energy Commission (AEC) on numerical terrain model generation. In another cooperative project, with Los Angeles County, a slope map of an eight-quadrangle area in the Santa Monica Mountains was made at 1:62,500 scale by this photomechanical process. Slope maps are also being produced as part of the San Francisco Bay region study.

In the interests of improving the accuracy of slope maps, a modified approach was tried in which the slope zones, as defined by photomechanically enhanced contours, are outlined by hand. This procedure reduces or eliminates spurious slope information in narrow hollows and along edges of water bodies. Preliminary results indicated this combination of manual and photomechanical compilation techniques may also be practical for use with contour copy of poor quality or in certain relief types, as karst areas or dunes.

Relief shading

In April 1971, the USGS first announced experiments in semiautomatic relief shading. During the past year, several mapping experiments in photomechanical generation of shaded relief were begun, including one 7½-minute map and one 15-minute map previously shaded by hand methods, one 7½-minute orthophotomap, and one 7½-minute area for which orthophotoimagery and 1:62,500-scale contouring are available. In relief shading, a prototype revolving illuminator is used. Initially, a contour negative, from which unidirectionally enhanced contours are derived, is partially modified by insertion of a mask which reduces the amount of exposure through the wider index contours. Thus, enhanced contour lines of nearly equal weight are produced. With contours thickened in the direction of assumed illumination and with a handmade mask which separates illuminated slopes from shaded slopes, the copy is diffused so that it resembles relief shading.

Digital equipment

The Bendix Datagrid Digitizer, purchased for the EROS user facility, was found to have more useful applications than expected. The instrument permits line or point coordinate data on graphic formats of up to 36 by 48 in. to be digitized on magnetic tape. The flexibility of the system was increased by addition of incremental recording modes and biaxial scaler functions which permit the machine distances and coordinates to be reduced or expanded to fit selected map scales. Last year the instrument was used for a number of interesting research applications, including geographic name indexing, compiling various data bases for planning and reporting, identifying land-use parcels, classifying shapes of shells and crystals, and checking map base dimensions.

Progress was made in developing a scanning instrument for converting contour drawings and other graphic information to digital form on magnetic tape. The optical and electronic components of the prototype model were assembled, but operational testing was delayed until an image tube for the special vidicon camera could be obtained. During the past year, a major research effort was begun in cooperation with Oak Ridge National Laboratories, Atomic Energy Commission, to explore applications of numerical terrain models that could be generated by the scanner. Initial efforts were focused on the conversion of contours into a digital terrain model of sufficient resolution to retain all meaningful hypsographic detail recorded on a 1:24,000-scale map. Computer programs for processing the data were written and tested. To test the programs, hand-generated data were used to form a digital terrain model of a 1-km block with a grid-cell spacing of 10 m. The Atomic Energy Commission provided software assistance in exploring applications of digital terrain models. The immediate interests of the USGS in utilizing terrain data were in the areas of generating profiles for orthophotomapping, converting contour drawings to different scales and intervals, and map revision.

Colorado Front Range mapping

The "Front Range Urban Corridor Map" for environmental, geologic, and hydrologic studies is a three-sheet series encompassing the strip of rapid urban development that runs north-south along the foot of the Colorado Front Range from Colorado Springs to Fort Collins—roughly 150 mi. Modeled to some extent after the San Francisco Bay region 1:125,000-scale series, the Front Range maps were drafted at 1:72,000 scale for reduction to 1:100,000. This process allowed simultaneous compilation and color-separation drawing on reduced-scale 7½-minute quadrangles, which are concurrently being revised. The publication scale of 1:100,000 was selected to be in line with future trends toward metric conversion.

The projection is Universal Transverse Mercator with UTM 5000-m grid ticks and State Plane Coordinate ticks at 50,000 ft along the neat line. One hundred feet was selected as the contour interval, with 50-ft supplementals as required. Roads are single line in varying weights to symbolize road classification. All streets are shown in red, which produces a tinted effect in urban areas. Only landmark buildings of prime importance are shown. Several tint plates will delimit areas of special interest. Woodland is taken directly from 7½-minute quadrangle manuscripts and retained without redrafting.

Phase mapping

All production offices of the Topographic Division participated in a research project to explore the economic, technical, and operational feasibility of producing quadrangle maps in three phases and publishing the products at the end of each phase. The first two products would provide map coverage in an incomplete form but on a timely and economical basis, the goal being to provide maximum map data in a given time period. The first product, a monochromatic orthophotoquad, is published as soon as possible after aerotriangulation and processing. It is printed in standard map format with a spatial referencing system and limited cartographic content, such as collar information and major place names. The second product is an orthophotoquad with contours and selected line detail that has been classified or verified by field investigation, such as names and labels, roads, drainage, and boundaries. The final product, a standard topographic (line) map or an orthophotomap, depends on the terrain type. Experimental phase mapping products are being prepared of test areas for distribution to the map-using public for evaluation and comment.

Research in orthophotomapping

Research last year was concentrated on use of high-altitude photographs and improvement of image quality. Several U-2 aircraft were available for civilian photographic flights, especially for mapping research. Quad-centered photographs (taken so that every other one is centered over a 7½-minute quadrangle) were attractive for both aerotriangulation and orthophotomapping. Significant advantages are improved production rate and uniform-tone imagery because no mosaicking is necessary.

Research in orthophotograph production established that it is possible to make excellent fine-grain continuous-tone reproductions on direct reversal, high-contrast line film. Use of a reversal line emulsion for continuous-tone copy requires two exposures, a flash and a normal timed exposure. By densitometric control, the two exposures are balanced to give the desired contrast and density from a wide variety of original photographs. Data are derived from densitometric curves to compute the correct flash and normal exposures. Advantages are (1) with densitometric control of exposure, contrast is determined by exposure, and the film acquires a variable, wide-range, contrast emulsion, and (2) although input may vary radically in contrast and density, processing remains constant.

The random-dot process is used to reproduce the continuous-tone imagery of orthophotomaps without screening. A newly devised process for producing random-dot images is much simpler than earlier processes. In the new process, a continuous-tone camera negative is contact printed by photolysis onto du Pont PFM matte film. Photolysis is the phenomenon by which silver halide is reduced to free (colloidal) silver by the action of light alone. The negative is exposed to an arc lamp for 10 to 15 min, and the film is put directly into hypo, washed, and dried. The resulting low-contrast positive is contact printed to high-contrast litho film (EK Type 3) which is machine developed in litho-type developer to produce the random-dot negative.

To make a left-reading printer for diazo reproduction, a duplicate negative is made, and then a contact positive. Contrast is sometimes a problem, but it can be controlled precisely by making the duplicate negative on EK High Speed Duplicating film and by adjusting the contrast by the flash technique.

The photolysis process is being used to provide masters for diazo printing of orthophotoquads and to prepare scribable photoimage bases for compilation, field completion, and revision. Further studies are underway to determine the usefulness of photolysis in monochrome and multicolor lithographic printing.

Areas for orthophotomap coverage

Past experience indicates that orthophotomaps have been most successful and most highly appreciated in swamp areas, desert areas, and the Prudhoe Bay area in Alaska, well known for its petroleum reserves. Last year, the Department of Housing and Urban Development (HUD) requested orthophotomap coverage of the urban areas of the United States. The request includes the Nation's 25 largest cities and encompasses about 56,000 sq mi.

Six orthophotomapping projects along the eastern coastland were in various stages of production, ranging from requisition for aerial photography to final scribing of contours and editing. All project areas had low relief, and therefore Orthophotoscope scanning was not required for the photographs. Only aerotriangulation, conventional rectification, and mosaicking were needed to prepare the orthophoto bases. Three projects used quad-centered 6-in. photographs at scales ranging from 1:76,000 to 1:84,000. Some imagery required mosaicking because of sunspots and mislocation of the exposure station. Usually, 6-in. photographs are preferred to super-wide-angle photographs for orthophotomapping because of superior resolution and more uniform tonal range. However, super-wide-angle photographs were satisfactory in two Florida project areas that have minimum planimetric detail. The extreme tonal ranges due to coral, marl, and mangrove and the subtle contrasts in marginal lands with a transition from wetlands to drylands cause difficulty in portraying photographic imagery in the printed maps.

Work was started on the production of 49 orthophotoquads in Arizona for the Bureau of Indian Affairs. They are being produced from 1:79,000-scale photographs taken with a KC-5A camera in the Air Force USQ-28 plane. Mosaic assemblies are controlled by fully analytical aerotriangulation, using either the Haag-Streit or the PG-2 coordinatograph for fast measurement of diapositives.

As a result of interest expressed by Illinois State officials, three different experimental orthophotomaps were started of the same areas in Chicago to determine the extent of problems in mapping tall buildings of urban areas. One sample orthophotomap is being made from photographs taken with a 12-in. camera at a flight height of 18,000 ft; a second sample, from photographs taken with a 12-in. camera at a flight height of 30,000 ft; and a third, from photographs taken with a 6-in. camera at a flight height of 12,000 ft. When the samples are completed and evaluated, orthophotomaps of eight additional adjacent areas will be prepared for the State under a cooperative funding agreement. The maps will be distributed to various metropolitan agencies for evaluations and recommendations.

Metrication study

A metrication work group was named to explore the overall effects on the National Topographic Program of converting to the metric system. Initial investigations indicate that the Topographic Division could easily adopt metric units for data and products, except for problems of contours and contour intervals. The work group planned further investigation on (1) contour interval series for metric maps, (2) the cost and feasibility of preparing two contour manuscripts, one in feet and the other in meters, and (3) the effects of metrication on topographic expression, readability, symbolization, and other cartographic details. As part of the investigation, a project was started to produce four experimental maps of the same area that will show the evolutionary steps of metric conversion. The samples are intended to help in determining scale, contour interval, and gridding of metric maps.

Second interim revision

Interim revision, in which planimetric detail is updated from recent photographs, but without field check, and shown in purple, has been applied to maps of predominantly urban-suburban areas since 1966. Ready acceptance of interim revision indicated that it might be practical and expedient to apply a second (consecutive) interim revision to selected maps, and a research project was undertaken to determine the best way of showing the second interim-revision data. The four 7½-minute quadrangles covering Des Moines, Iowa, mapped in 1956 and interim revised in 1967, were chosen for the research project. The new photographs were taken in 1971, and the second interim-revision data were compiled on separate manuscripts. Two final color proofs were processed, one showing the first interim revision in purple and the second revision in orange and the other showing both revisions in purple. Other colors were rejected as lacking contrast with normal colors. On evaluation, orange was also rejected because it lacked satisfactory contrast and the multiplicity of colors impaired the legibility of the map. Purple was therefore chosen as the color for second interim revision, to match the first, but the data are to be compiled on separate manuscripts so that map users who need the information provided by successive updatings for progressive studies can obtain copies of the separated data. A policy statement on second interim revisions was issued in March 1972.

Note.—See also the section "Applications to Cartographic Studies" on pages A191–A195 under "Remote Sensing and Advanced Techniques."

COMPUTER TECHNOLOGY

During fiscal year 1972, the USGS continued to add capabilities to the Computer Center's facilities and expand its availability.

New computer terminals were added in Bay St. Louis, Miss.; Philadelphia, Pa.; Austin, Tex.; Tucson, Ariz.; Metairie, La.; St. Louis, Mo.; and Garden Grove, Calif. These new terminals will expand the ability of the USGS researchers and their cooperators to access the rapidly developing data bases and to perform computational work at the central computing facility in Washington, D. C.

EQUIPMENT

Major modifications are being made to the central computing facility. Disk storage capability is being expanded by eight spindles. An additional million bytes of core storage is being added to the IBM 360/65 computer giving a total of 2 million bytes. A flatbed plotter with a 4- by 5-ft plotting surface will be installed in the summer 1972. This together with new plotter software will permit high plotting accuracy on a large surface area.

A new Scan-Data 200 optical page reader has been installed and is operational. This scanner system has the ability to read IBM 1403 and optical character recognition OCR-A and OCR-B (upper and lowercase) type fonts. In addition, the machine will read handprinted numerics and limited alphabetics. Processing speed is approximately 2½ times the speed of the scanner that was replaced. This new scanner system will permit a wide variety of data input and editing.

GRAPHICS

In response to a significant requirement for increased graphics capabilities, the Computer Center is establishing a graphics laboratory. Plotters, digitizers, and interactive CRT terminals will be available in three locations: Washington, D.C.: Denver, Colo.; and Menlo Park, Calif. The equipment, basic program routines, and programmer assistance will be available to support the application of graphics to specific project requirements. In addition, research into various methods of graphic data presentation will be undertaken to provide information to potential users. To support the effort in graphics, the following equipment has been acquired:

1. Tektronix 4010-1 Computer Display Terminals, which are interactive graphics terminals using a storage CRT for display of a matrix of 1024 by 780 viewable points. Interaction between the terminal user and the stored data is provided through a thumb-wheel-operated cursor or through a digitizer. A printed copy of the screen display can be obtained by use of the associated hard-copy unit.
2. Digitizer tablets, which provide a convenient way to enter data by tracing curves, by touching single points, or by entering locations of points composing an image. The tablets accommodate a data source, such as an area of a map, up to 11.25 by 11.25 in. and are connected to Tektronix terminals to allow data to be entered directly into the computer.
3. Hewlett-Packard 7202A Graphic Plotters, which are small flatbed plotters attached to low-speed terminals. The size of the plot can range from 5 by 5 in. to 10 by 15 in.

USER TECHNICAL SUPPORT

Inquiry and Reporting System (Super-Query) has been implemented on the computer system. This is an advanced general purpose information management system. It is designed to provide the user with a fast, efficient, and easy-to-use technique for extracting information from computer files, performing basic data processing operations, and producing card, printer, tape, and disk output.

NEW APPLICATIONS

Minicomputer system for a mass spectrometer laboratory

The Branch of Isotope Geology has set up a PDP-11 minicomputer system which is used for processing data from several mass spectrometers to provide accurate measurement of isotope ratios from geologic samples. The isotope ratios of interest provide information about the age and geochemical history of such samples. Funds for the computer system were provided by NASA for work on the lunar samples.

The PDP-11 system comprises a central processor operating with 16,000 16-bit words of core memory and 256,000 16-bit words of disk memory. Other peripheral equipment includes a DEC magnetic-tape unit, a high-speed paper-tape reader and punch, and two teletypes. An extended arithmetic unit provides hardwired facilities for multiplication and division.

The analog signals from the mass spectrometers provide baseline and peak height information which is presently converted to digital form by two separate digital voltmeter systems. One of these systems integrates signals over a period of 1 sec and records, on paper tape, a six-digit voltage together

with a peak number once every 2 sec. On completion of an analysis, which takes 15 to 20 min, the paper tape is read into the computer. The required isotope ratios are computed, and output is on teletype with almost immediate turnaround. The other integrating six-digit voltmeter system includes a scanner unit which permits the single voltmeter to sequentially sample the outputs of up to three mass spectrometers operating simultaneously. The voltmeter will perform up to 40 integrations per second (each integration period being one-sixtieth of a second), and this data is fed directly onto the PDP-11 disk in 12-character word format. Separate files are allocated for the data from each spectrometer. At the end of an analysis, isotope ratios are computed and transmitted to the appropriate teletype.

The mass spectrometers can analyze different elements which may contain different numbers of isotopes and may require different types of corrections to the peak heights before the isotope ratios are computed. Programs have been written for strontium, lead, uranium, thorium, and argon analyses. The computations for each element are so sufficiently similar that all analyses may be processed from a series of common subroutines. For each type of analysis, the appropriate subroutines are called sequentially into the core using the overlay system available in the PDP-11 software.

The computations include routines for averaging data into 1-sec points and for rejecting spurious data from individual peak tops by successively fitting least-square straight lines; baseline and minor peak-height corrections and calculations of isotope ratios and their standard deviations are made by linear interpolation.

Urban information systems—feasibility study

An urban information systems—feasibility study was initiated on October 11, 1971, as a part of the San Francisco Bay region environment and resources planning study. (See "Urban Area Studies.") As an initial project activity carried on consecutively to a state-of-the-art library search, a preliminary study of the earth-science data to be digitized was made by conducting an inventory of the various interpretive studies underway at the time of the San Francisco Bay region program. The rough scientific data used in these studies are primarily maps of basic information, such as topographic maps and geologic maps, but also include tabular information. From the point of view of digitization, the information, whether interpretive or rough, can be classified as follows:

1. Areal or zonal information, such as land use zones or bedrock zones.
2. Line information such as contour lines or streets.
3. Point information such as well locations.
4. Tabular information such as engineering properties of soil.

It was decided that the problem of digitization could be studied independently of the class of data being digitized as long as the four classes listed above could be handled. As a result major methods of digitizing maps have been identified, and detailed information is being obtained. Major methods for organizing an earth-science data base have also been identified. Two urban and regional information systems are to be studied. These are the Metropolitan Transportation Commission and that of Santa Clara County. Initial contacts have been made and some preliminary information obtained. A part of the study is to indicate solutions to the problems interfacing urban and regional information systems and the earth-science data bank. Within the limits of time and available information, comparative cost estimates will be made for establishing and maintaining an earth-science data bank for the nine-county bay area, considering various factors such as method of digitization, organization of the data base, accuracy required (size of the data bank) versus payoff, and so forth.

Unsaturated Darcian flow by the Galerkin method

This program calculates the unsaturated Darcian flow of water into a horizontal cylinder, initially filled with dry sand. The solution is obtained by the Galerkin method. The program was developed as a prototype application of Galerkin methods to nonlinear, parabolic, boundary-value problems in a three-dimensional, cylindrical coordinate system. The program is freely innovative in the use of complex Galerkin base functions, the calculation of projections by mechanized analytic integration, and the reduction of the three-dimensional problem to a quasi-one-dimensional problem. The techniques explored in this program may contribute to the theory of unsaturated flow of water in soils and in future programs may be applied to the analysis of pollution in estuaries and to the heating of river water by nuclear reactors.

Environmental analysis model: United States energy

This program calculates the transient response of a feedback network. It is based on a model by J. W. Forrester (1971) but is tailored to represent the environmental impact of energy consumption in the United States. The program was developed under the direction of R. R. Doell (USGS) for use on an interactive timesharing terminal. The program produces time plots of population, pollution, energy resources, capital investment, food supply, quality of life, and other environmental variables for output on the terminal printer. The rapid response of the timesharing system permits computerized experimentation with various energy-consumption policies to determine their impact on the U.S. environment over the next century.

Note.—See entries under "Computer technology" in "Subject Index," page A301, for specific applications of computer technology.

U.S. GEOLOGICAL SURVEY PUBLICATIONS

PUBLICATIONS PROGRAM

Books and maps

Results of research and investigations by the U.S. Geological Survey are made available to the public through professional papers, bulletins, water-supply papers, circulars, miscellaneous reports, and several map and atlas series, most of which are published by the Geological Survey. Of these reports, books are printed and sold by the U.S. Government Printing Office, and maps are printed and sold by the Survey.

All books, maps other than topographic quadrangle maps, and related Geological Survey publications are listed in the catalogs "Publications of the Geological Survey, 1879-1961" and "Publications of the Geological Survey, 1962-1970" and in yearly supplements, available on request, that keep the catalogs up to date.

New publications, including topographic quadrangle maps, are announced monthly in "New Publications of the Geological Survey." A free subscription to this list may be obtained on application to the U.S. Geological Survey, Washington, D.C. 20242.

State lists of publications on hydrology and geology

"Geologic and Water-Supply Reports and Maps, [State]," a series of booklets, provides a ready reference to these publications on a State basis. The booklets also list libraries in the subject State where Geological Survey reports and maps may be consulted; these booklets are available free on request to the Geological Survey.

Surface-water and quality-of-water records

Beginning with the 1961 water year, surface-water records have been released on a State-boundary basis in separate annual reports entitled "Water Resources Data for [State]: Part 1, Surface Water Records." The records will also be published in the Geological Survey series of water-supply papers at 5-year intervals. The first group of "Surface Water Supply" papers covers the water years 1961–65.

Publication of quality-of-water records began in the annual State series in 1964 as "Water Resources Data for [State]: Part 2, Water Quality Records." The annual publication in the Geological Survey water-supply papers of "Quality of Surface Water of the United States" by drainage basins has been continued. Distribution of the State water-resources data, Parts 1 and 2, is limited and primarily for local needs. These reports are free on request to Water Resources Division district offices (listed on p. A257–A258) in areas for which records are needed.

Indexes, by drainage basins, of surface-water records to September 30, 1967, are published in the Geological Survey series of circulars, issues of which are free on application to the U.S. Geological Survey, Washington, D.C. 20242. These indexes list all streamflow and reservoir stations for which records have been published in Geological Survey reports.

"Index of Water Quality Stations, Water Year 1972," lists all the stations at which water-quality data were collected for the 1972 water year. This inventory may also be obtained free from the Survey.

State water-resources investigations folders

A series of folders entitled "Water Resources Investigations in [State]" is a project of the Water Resources Division to inform the public about its current program in the 50 States and Puerto Rico, the Virgin Islands (U.S.), Guam, American Samoa, and Okinawa. As the programs change, the folders are revised. The folders are available free on request to the U.S. Geological Survey, Washington, D.C. 20242, or to the Water Resources Division district offices listed on pages A257–A258.

Open-file reports

Open-file reports, which consist of manuscript reports, maps, and other preliminary material, are made available for public consultation and use. Arrangements can generally be made to reproduce them at private expense. The date of release and places of availability for consultation by the public are given in press releases or other forms of public announcement. A Survey publication, listing all reports and maps released only in the open files, is published annually in the circular series. Most open-file reports are placed in one or more of the three Geological Survey libraries: 1033 General Services Bldg., Washington, D.C.; Bldg. 25, Federal Center, Denver, Colo.; and 345 Middlefield Road, Menlo Park, Calif. Other depositories may include one or more of the Geological Survey offices listed on pages A253–A259 and interested State agencies. Many open-file reports are superseded later by formally printed publications.

PUBLICATIONS ISSUED

During fiscal year 1971, the Geological Survey published 5,176 maps, comprising some 18,150,200 copies, and 278 technical book reports.

Kind of Map	1972
Topographic	4,802
Geologic and hydrologic	190
Maps for inclusion in book reports	73
Miscellaneous (includes maps for other agencies)	111
Total	5,176

In addition, 1093 leaflets and maps of flood-prone areas were published.

At the beginning of the fiscal year, more than 87 million copies of maps and book reports were on hand in the Geological Survey's distribution centers. During the year 9,537,500 copies of maps, including 584,000 index maps, were distributed. Approximately 6.2 million maps were sold, and $2,247,709 was deposited to Miscellaneous Receipts in the U.S. Treasury.

The Survey also distributed 464,600 copies of technical book reports, without charge and for official use, and 1,708,000 copies of booklets, free of charge, chiefly to the general public; 197,000 copies of the monthly publications announcements and 208,000 copies of a sheet showing topographic map symbols were sent out.

The total distribution resulted from receipt of 533,400 individual orders. The following table compares Survey map and book distribution (including bookets but excluding symbol sheets and monthly announcements) during fiscal year 1971 and 1972:

Distribution points	Fiscal year 1971	Fiscal year 1972	Change (Percent)
Eastern (Arlington, Va.)	5,918,043	6,347,842	+7
Western (Denver, Colo.)	4,601,092	5,029,615	+9
Alaska (Fairbanks)	80,887	113,590	+40
12 other Survey offices	801,046	809,283	+1
Total	11,401,068	12,300,330	+8

HOW TO OBTAIN PUBLICATIONS

OVER THE COUNTER

Book reports

Book reports currently in print (professional papers, bulletins, water-supply papers, "Topographic Instructions," "Techniques of Water Resources Investigations," and some miscellaneous reports) can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D.C., and from the Geological Survey Public Inquiries Offices listed on page A253.

Maps and charts

Maps and charts may be purchased at the following U.S. Geological Survey offices:

1200 S. Eads St., Arlington, Va.
Room 1028, General Services Bldg., 19th and F Sts., N.W., Washington, D.C.
1109 N. Highland St., Arlington, Va.
900 Pine St., Rolla, Mo.
Building 41, Federal Center, Denver, Colo.
345 Middlefield Rd., Menlo Park, Calif.
Room 441 Federal Building, 710 W. 9th St., Juneau, Alaska
310 1st Ave., Fairbanks, Alaska
Public Inquiries Offices listed on page A253.

Geological Survey maps are also sold by nearly 1,000 authorized commercial dealers throughout the United States. Prices charged are generally higher than those charged by Geological Survey offices.

Indexes showing topographic maps published for each State, Puerto Rico, the Virgin Islands (U.S.), Guam, and American Samoa are available free on request. Publication of revised indexes to topographic mapping is announced in the monthly "New Publications of the Geological Survey." Each index also lists special and United States maps, as well as Geological Survey offices from which maps may be purchased and local dealers who sell the Survey's maps.

BY MAIL

Book reports

Technical book reports, certain leaflets in bulk quantity, and some miscellaneous reports can be ordered from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402. Prepayment is required and should be made by check or money order payable to the Superintendent of Documents. Postage stamps are not accepted; cash is sent at the sender's risk. On orders of 100 copies or more of the same reports, a 25-percent discount is allowed. Circulars and some miscellaneous reports may be obtained free from the U.S. Geological Survey, Washington, D.C. 20242.

Maps and charts

Maps and charts, including folios and hydrologic atlases, are sold by the Geological Survey. Address orders to Distribution Section, U.S. Geological Survey, 1200 S. Eads St., Arlington, Va. 22202, for maps of areas east of the Mississippi River, including Puerto Rico and the Virgin Islands (U.S.), and to Distribution Section, U.S. Geological Survey, Federal Center, Denver, Colo. 80225, for maps of areas west of the Mississippi,

including Alaska, Hawaii, Louisiana, Minnesota, Guam, and American Samoa. An order for both eastern and western maps should be sent to the closer of the two distribution sections listed above. Residents of Alaska may order Alaska maps from Distribution Section, U.S. Geological Survey, 310 1st Ave., Fairbanks, Alaska 99701.

Prepayment is required. Remittances should be by check or money order payable to the U.S. Geological Survey. Prices are quoted in lists of publications and, for topographic maps, in indexes to topographic mapping for individual States. Prices include the cost of surface transportation.

Advance material from mapping

Advance material available from current topographic mapping is indicated on individual State index maps which are issued quarterly. This material, which includes such items as aerial photography, geodetic control data, and maps in various stages of preparation and editing, is available for purchase. Information concerning the ordering of these items is contained in the text of the indexes. Requests for the indexes or inquiries concerning the availability of advance material should be directed to the Map Information Office, U.S. Geological Survey, Washington, D.C. 20242.

EROS Data Center materials

Geological Survey aerial photography, NASA aircraft photography and imagery, and ERTS imagery are sold by the Geological Survey, as are copies of the photography and imagery produced on 16-mm browse film, which are designed to provide prepurchase evaluation. Address requests for current price list, additional information, and orders to: EROS Data Center, U.S. Geological Survey, Sioux Falls, S. Dak. 57198. Prepayment is required for orders. Remittances should be made payable to the U.S. Geological Survey.

National Technical Information Service

Some Geological Survey reports, including computer programs, data and information supplemental to map or book publications, and data files, are released through the National Technical Information Service. These reports, available either in paper copies or in microfiche, or sometimes on magnetic tapes, can be purchased only from National Technical Information Service, U.S. Department of Commerce, Springfield, Va. 22151. Geological Survey reports that are released through NTIS, together with their NTIS order numbers and prices, are announced in the monthly "New Publications of the Geological Survey."

PUBLICATIONS OUT OF PRINT

Book publications listed as out of print can no longer be obtained from the Superintendent of Documents, Washington, D.C. However, some books listed as out of print are available for purchase from his authorized agents: U.S. Geological Survey offices at 1012 Federal Building, 1961 Stout St., Denver, Colo. 80202; 8102 Federal Office Building, 125 S. State St., Salt Lake City, Utah 84111; Room 1C45, 1100 Commerce St., Dallas, Tex. 75202; 7638 Federal Building, 300 N. Los Angeles St., Los Angeles, Calif. 90012; 504 Custom House, 555 Battery St., San Francisco, Calif. 94111; 678 U.S. Court House Building, West 920 Riverside Ave., Spokane, Wash. 99201; and 108 Skyline Building, 508 2nd Ave., Anchorage, Alaska 99501.

Maps, charts, folios, and atlases that are out of print can no longer be obtained from any official source. These may be consulted at many libraries, and some can be purchased from secondhand-book dealers.

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COOPERATORS AND OTHER FINANCIAL CONTRIBUTORS DURING FISCAL YEAR 1972

[Cooperators listed are those with whom the U.S. Geological Survey had a written agreement for fiscal cooperation in fiscal year 1972, cosigned by the Director of the Geological Survey and a responsible official of the cooperating agency. Agencies with whom the Geological Survey had research contracts and to whom it supplied funds for such research are not listed. Parent agencies are listed separately from their subdivisions where separate cooperative agreements for different projects were made with the parent agency and with a subdivision of the parent agency]

FEDERAL COOPERATORS

Agency for International Development
Atomic Energy Commission:
- Albuquerque Operations Office
- Division of Applied Technology
- Division of Headquarters Services
- Division of Peaceful Nuclear Explosives
- Division of Reactor Development and Technology
- Idaho Operations Office
- Knolls Atomic Power Laboratory
- Nevada Operations Office
- Office of Regulation
- Richland Operations Office
- San Francisco Operations Office
- Savannah River Operations Office
- Schenectady Naval Operations Office

Department of Agriculture:
- Agriculture Research Service
- Forest Service
- Soil Conservation Service

Department of the Air Force:
- Alaskan Air Command
- Cambridge Research Laboratory
- Headquarters (AFTAC/AC)
- Homestead Air Force Base
- North Air Force Base
- Office of Scientific Research
- Special Weapons Center
- Vandenburg Air Force Base
- Warner Robins Air Force Base

Department of the Army:
- Army Research Office
- Cold Regions Research and Engineering Laboratory
- Corps of Engineers
- Pueblo Army Depot
- White Sands Missile Range

Department of Commerce:
- National Marine Fisheries Service
- National Oceanic Survey
- National Weather Service

Department of Defense:
- Advanced Research Projects Agency
- Defense Nuclear Agency

Department of Health, Education, and Welfare, Public Health Service

Department of Housing and Urban Development

Department of the Interior:
- Alaska Power Administration
- Bonneville Power Administration
- Bureau of Indian Affairs
- Bureau of Land Management
- Bureau of Mines
- Bureau of Reclamation
- Bureau of Sport Fisheries and Wildlife
- National Park Service
- Office of Water Resources Research

Department of the Navy:
- Key West Naval Station
- Marine Corps, Camp Pendleton
- Marine Corps Supply Center
- Naval Oceanographic Office
- Naval Weapons Center
- Office of Naval Petroleum and Oil Shale Reserves
- Office Of Naval Research
- Public Works Center, Guam

Department of State:
- International Boundary and Water Commission
- International Joint Commission

Environmental Protection Agency, Office of Water Programs

National Aeronautics and Space Administration

National Science Foundation, National Center for Atmospheric Research

Office of Emergency Preparedness

Tennessee Valley Authority
Water Resources Council

STATE, COUNTY, AND LOCAL COOPERATORS

Alabama:
- Alabama Highway Department
- City of Mobile
- Geological Survey of Alabama

Alaska:
- Alaska Department of Highways
- Alaska Department of Natural Resources
- City and Borough of Juneau
- City of Anchorage
- Department of Environmental Conservation
- Greater Anchorage Area Borough
- Kenai Borough

Arizona:
- Apache County Superior Court
- Arizona Game and Fish Department
- Arizona Highway Department
- Arizona Water Commission
- Buckeye Irrigation Company
- City of Flagstaff
- City of Safford
- City of Tucson
- City of Williams
- Flood Control District of Maricopa County
- Gila Valley Irrigation District
- Maricopa County Municipal Water Conservation District No. 1
- Navajo Tribal Council
- Navajo Tribal Utility Authority
- Pima County Board of Supervisors
- Salt River Valley Water Users' Association
- San Carlos Irrigation and Drainage District
- Show Low Irrigation Company

Arkansas:
- Arkansas Department of Pollution Control and Ecology
- Arkansas Geological Commission
- Arkansas State Highway Commission

California:
- Alameda County Flood Control and Water Conservation District
- Alameda County Water District
- Antelope Valley-East Kern Water Agency
- Berrenda Mesa Water District
- California Department of Conservation, Division of Mines and Geology
- California Department of Water Resources
- California Division of Highways, Materials and Research Department
- California Water Resources Control Board
- Casitos Municipal Water District
- City of Modesto, Public Works Department
- City of San Diego
- City of San Rafael
- City of Santa Barbara
- City of Santa Cruz
- Coachella Valley County Water District
- Contra Costa County Flood Control and Water Conservation District
- County of Sacramento, Department of Public Works
- County of San Diego, Board of Supervisors
- County of San Mateo
- Desert Water Agency
- East Bay Municipal Utility District
- Georgetown Divide Public Utility District
- Goleta County Water District
- Imperial Irrigation District

California—Continued
- Indian Wells Valley County Water District
- Irvine Ranch Water District
- Lake County Flood Control and Water Conservation District
- Los Angeles County, Department of County Engineers
- Los Angeles County Flood Control District
- Los Angeles Department of Water and Power
- Madera County Flood Control and Water Conservation Agency
- Madera Irrigation District
- Metropolitan Water District of Southern California
- Mojave Water Agency
- Montecito County Water District
- Monterey County Flood Control and Water Conservation District
- Napa County Flood Control and Water Conservation District
- Orange County Flood Control District
- Orange County Water District
- Paradise Irrigation District
- Placer County Department of Public Works
- Riverside County Flood Control and Water Conservation District
- San Benito County Water Conservation and Flood Control District
- San Bernardino County Flood Control District
- San Bernardino Valley Municipal Water District
- San Francisco City and County Public Utilities Commission
- San Francisco Water Department
- San Luis Obispo County Engineering Department
- Santa Barbara County Flood Control and Water Conservation District
- Santa Barbara County Water Agency
- Santa Clara County Flood Control and Water District
- Santa Cruz County Flood Control and Water Conservation District
- Santa Margarita and San Luis Rey Watershed Planning Agencies
- Santa Maria Valley Water Conservation District
- Santa Ynez River Water Conservation District
- Siskiyou County Flood Control and Water Conservation District
- Solana Irrigation District
- Tehachapi—Cummings County Water District
- Terra Bella Irrigation District
- Tulare County Flood Control District
- Turlock Irrigation District
- United Water Conservation District
- University of California, School of Forestry and Conservation
- Ventura County Flood Control District
- Western Municipal Water District
- Woodbridge Irrigation District
- Yolo County Flood Control and Water Conservation District

Colorado:
- Arkansas River Compact Administration
- City of Aspen
- City of Aurora, Department of Public Utilities
- City of Colorado Springs, Department of Public Utilities

Colorado—Continued
- City and County of Denver, Board of Water Commissioners
- Colorado Department of Health, Water Pollution Control Commission
- Colorado Division of Water Resources, Office of the State Engineer
- Colorado River Water Conservation District
- Colorado State Mining Industrial Development Board
- Colorado Water Conservation Board
- Regional Transportation District
- Southeastern Colorado Water Conservancy District
- State of Colorado, Department of Highways
- Urban Drainage and Flood Control District

Connecticut:
- City of Hartford, Department of Public Works
- City of New Britain, Board of Water Commissioners
- City of Torrington
- Connecticut Geological and Natural History Survey
- Department of Agriculture and Natural Resources
- Department of Environmental Protection
- Department of Transportation
- Southeastern Connecticut Water Authority
- State of Connecticut, Office of State Planning

Delaware:
- Delaware Geological Survey, University of Delaware
- Department of Highways and Transporation, Division of Highways

District of Columbia:
- Department of Environmental Services

Florida:
- Board of Trustees of the Internal Improvement Trust Fund
- Broward County
- Broward County Air and Water Pollution Control Board
- Central and Southern Florida Flood Control District
- City of Boca Raton
- City of Clearwater
- City of Cocoa
- City of Deerfield Beach
- City of Fort Lauderdale
- City of Fort Myers
- City of Gainesville
- City of Hallandale
- City of Hollywood
- City of Jacksonville
- City of Miami, Department of Water and Sewers
- City of Miami Beach
- City of Pensacola
- City of Perry
- City of Pompano Beach
- City of Riviera Beach
- City of St. Petersburg
- City of Sarasota
- City of Tallahassee
- City of Venice
- Collier County
- Collier County Water District No. 1
- Collier County Water District No. 7
- Dade County Department of Public Works

Florida—Continued
- Dade County Water and Sewer Authority
- East Central Florida Regional Planning Council
- Englewood Water District
- Escambia County
- Florida Department of Natural Resources, Bureau of Geology
- Florida Department of Transportation
- Florida Division of Parks and Recreation
- Hillsborough County
- Jacksonville Area Planning Board
- Lake County
- Lee County
- Marion County
- Orange County
- Osceola County
- Palm Beach County
- Pinellas County
- Polk County
- Reedy Creek Improvement District
- Seminole County
- Southwest Management District
- Suwanee River Authority
- Tampa Port Authority
- Trustees of the Internal Improvement Trust Fund
- Volusia County
- Walton County

Georgia:
- Chatham County
- City of Brunswick
- Georgia Department of Mines, Mining, and Geology
- Georgia Water Quality Control Board
- Savannah County
- State Highway Department

Hawaii:
- City and County of Honolulu
- Honolulu Board of Water Supply
- State Department of Land and Natural Resources
- State Department of Transportation

Idaho:
- City of Kellogg
- Idaho Department of Highways
- Idaho Department of Water Administration

Illinois:
- City of Springfield
- County of Cook, Forest Preserve District
- Fountain Head Drainage District
- Illinois Institute of Environmental Quality
- Illinois State Water Survey
- McHenry County Regional Planning Commission
- Northeastern Illinois Planning Commission
- Sanitary District of Bloom Township
- State Department of Registration and Education:
  - Illinois State Geological Survey
- State Department of Transportation:
  - Division of Highways
  - Division of Waterways
- The Metropolitan Sanitary District of Greater Chicago
- University of Illinois at Urbana-Champaign

Indiana:
- Indiana Board of Health
- Indiana Department of Natural Resources
- Indiana Highway Commission

Iowa:
- City of Cedar Rapids
- City of Des Moines
- City of Fort Dodge
- Iowa Geological Survey
- Iowa Natural Resources Council
- Iowa State Highway Commission, Highway Research Board
- Iowa State University
- Iowa State University, Agricultural and Home Economics Experiment Station
- Linn County
- University of Iowa
- University of Iowa, Institute of Hydraulic Research

Kansas:
- City of Wichita
- Kansas State Department of Health
- Kansas State Water Resources Board
- Kansas-Oklahoma Arkansas River Commission
- State Geological Survey of Kansas
- State Highway Commission of Kansas

Kentucky:
- Kentucky Geological Survey, University of Kentucky
- University of Kentucky Research Foundation

Louisiana:
- Louisiana Department of Highways
- Louisiana Department of Public Works
- Sabine River Authority of Louisiana

Maine:
- Maine Public Utilities Commission
- Maine State Highway Commission

Maryland:
- City of Baltimore, Water Division
- Maryland Department of Health and Mental Hygiene
- Maryland Department of Transportation, The State Highway Administration
- Maryland Geological Survey
- Maryland National Capital Park and Planning Commission
- Montgomery County
- Washington Suburban Sanitary Commission

Massachusetts:
- Department of Public Works:
  - Division of Highways
  - Division of Waterways
- Metropolitan District Commission
- State Water Resources Commission:
  - Division of Water Pollution Control
  - Division of Water Resources

Michigan:
- Michigan Department of Natural Resources:
  - Geological Survey Division
  - Water Resources Commission

Minnesota:
- Metropolitan Council of the Twin Cities Area
- Minnesota Department of Administration, Minnesota Geological Survey
- Minnesota Department of Highways
- Minnesota Department of Natural Resources, Division of Waters, Soils, and Minerals
- Minnesota Department of Iron Range Resources and Rehabilitation

Mississippi:
- City of Jackson
- Harrison County Board of Supervisors
- Harrison County Development Commission
- Jackson County Board of Supervisors
- Mississippi Air and Water Pollution Control Commission
- Mississippi Board of Water Commissioners
- Mississippi Geological Survey
- Mississippi Research and Development Center
- Mississippi State Highway Department
- Pat Harrison Waterway District
- Pearl River Basin Development District
- Pearl River Valley Water Supply District

Missouri:
- Curators of the University of Missouri
- Metropolitan St. Louis Sewer District
- Missouri Department of Business and Administration, Division of Geological Survey and Water Resources
- Missouri State Highway Commission
- Missouri Water Pollution Board
- St. Louis County

Montana:
- Endowment and Research Foundation—Montana State University
- Lewis and Clark County, Board of County Commissioners
- Montana Bureau of Mines and Geology
- Montana Department of Health and Environmental Sciences
- Montana State Fish and Game Department
- Montana State Highway Commission
- Montana Water Resources Board

Nebraska:
- City of Grand Island
- Clay County Ground Water Conservation District
- Hamilton County Ground Water Conservation District
- Nebraska Department of Water Resources
- Nebraska Game and Parks Commission
- Salt Valley Watershed District
- Seward County Ground Water Conservation District
- State Department of Roads
- University of Nebraska, Conservation and Survey Division
- York County Ground Water Conservation District

Nevada:
- Nevada Bureau of Mines
- Nevada Department of Conservation and Natural Resources
- Nevada State Highway Department

New Hampshire:
- New Hampshire Department of Resources and Economic Development
- New Hampshire Water Resources Board

New Jersey:
- County of Bergen
- Delaware River Basin Commission
- Mercer County
- New Jersey Department of Agriculture, State Soil Conservation Committee
- New Jersey Department of Environmental Protection:
  - Division of Fish, Game, and Shellfisheries
  - Division of Marine Services
  - Division of Water Resources
- North Jersey District Water Supply Commission
- Passaic Valley Water Commission

New Mexico:
- Albuquerque Metropolitan Arroyo Flood Control Authority
- City of Las Cruces
- Costilla Creek Compact Commission
- Interstate Stream Commission
- New Mexico Bureau of Mines and Mineral Resources
- New Mexico State Engineer
- New Mexico State Highway Commission
- Pecos River Commission
- Rio Grande Compact Commission

New York:
- Board of Hudson River—Black River Regulating District
- Central New York State Parks Commission
- City of Albany
- City of Auburn
- City of New York, Board of Water Supply
- County of Dutchess, Dutchess County Civil Defense
- County of Nassau, Department of Public Works
- County of Onondaga:
  - Department of Public Works
  - Water Authority
- County of Suffolk:
  - Department of Environmental Control
  - Water Authority
- County of Ulster, Ulster County Legislature
- County of Westchester, Department of Public Works
- Department of Environmental Conservation:
  - Environmental Management
  - Environmental Quality
- Department of Transportation
- New York State Department of Health
- New York State Education Department, Museum and Science Service
- Oswegatchie-Cranberry Reservoir Commission
- Power Authority of the State of New York
- Town of Brighton
- Town of Clarkstown
- Town of Warwick
- Village of Nyack

North Carolina:
- City of Asheville, Public Works Department
- City of Burlington
- City of Charlotte
- City of Durham, Department of Water Resources

North Carolina—Continued
- City of Greensboro
- City of Winston-Salem
- North Carolina Department of Conservation and Development, Division of Mineral Resources
- North Carolina Department of Natural and Economic Resources, Division of Mineral Resources
- North Carolina Department of Water and Air Resources
- State Highway Commission
- Town of Waynesville

North Dakota:
- North Dakota Geological Survey
- Oliver County, Board of County Commissioners
- State Highway Department
- State Water Commission
- University of North Dakota

Ohio:
- City of Columbus, Department of Public Service
- Miami Conservancy District
- Ohio Department of Health
- Ohio Department of Highways
- Ohio Department of Natural Resources
- Ohio State University Research Foundation
- Three Rivers Watershed District

Oklahoma:
- City of Oklahoma City, Water Department
- Oklahoma Department of Highways
- Oklahoma Geological Survey
- Oklahoma Soil Conservation Board
- Oklahoma Water Resources Board
- State Department of Health, Environmental Health Service

Oregon:
- Burnt River Irrigation District
- City of Astoria
- City of Eugene, Water and Electric Board
- City of McMinnville, Water and Light Department
- City of Portland, Bureau of Water Works
- City of The Dalles
- City of Toledo
- Coos County, Board of Commissioners
- Coos Bay-North Bend Water Board
- Douglas County
- Lakeside Water District
- Lane County, Department of General Administration
- Oregon State Board of Higher Education
- Oregon State Engineer
- Oregon State Game Commission
- Oregon State Highway Commission
- Water Resources Department

Pennsylvania:
- Chester County Commissioners
- Chester County Health Department
- Chester County Water Resources Authority
- City of Bethlehem
- City of Easton
- City of Harrisburg
- City of Philadelphia, Water Department
- Delaware River Master

Pennsylvania—Continued
- Pennsylvania Department of Environmental Resources
- Bureau of Topographic and Geologic Survey
- Bureau of Water Quality Management
- Office of Engineering and Construction
- State Soil and Water Conservation Commission
- Pennsylvania Department of Transportation
- Pennsylvania State University, College of Earth and Mineral Sciences

Rhode Island:
- City of Providence, Department of Public Works
- State Department of Natural Resources:
  - Division of Fish and Wildlife
  - Division of Planning and Development
- State Department of Transportation, Division of Roads and Bridges
- State Water Resources Board

South Carolina:
- Commissioners of Public Works, Spartanburg Water Works
- State Development Board
- State Highway Department
- State Pollution Control Authority
- State Public Service Authority
- State Water Resources Commission

South Dakota:
- Black Hills Conservancy Subdistrict
- City of Sioux Falls
- East Dakota Conservancy Subdistrict
- South Dakota Department of Highways
- South Dakota State Geological Survey
- South Dakota State Water Resources Commission

Tennessee:
- City of Chattanooga
- City of Lawrenceburg
- City of Memphis, Board of Light, Gas, and Water Commissioners
- Metropolitan Government of Nashville and Davidson County
- Murfreesboro Water and Sewer Department
- Tennessee Department of Conservation:
  - Division of Geology
  - Division of Water Resources
- Tennessee Department of Highways
- Tennessee Department of Public Health, Division of Water Quality Control
- Tennessee Game and Fish Commission

Texas:
- City of Dallas, Public Works Department
- City of Fort Worth
- City of Houston
- County of Dallas
- Sabine River Authority of Texas
- Sabine River Compact Administration
- Texas Highway Department
- Texas Water Development Board

Utah:
- Bear River Commission
- Salt Lake County
- State Department of Highways

Utah—Continued
- State Department Natural Resources, Division of Water Rights
- Utah Geological and Mineralogical Survey

Vermont:
- State Department of Highways
- State Department of Water Resources, Planning and Development Division
- Vermont Geological Survey

Virginia:
- City of Alexandria
- City of Newport News, Department of Public Utilities
- City of Norfolk, Department of Utilities
- City of Norfolk, Division of Water Supply
- City of Roanoke
- City of Staunton
- County of Chesterfield
- County of Fairfax
- Virginia Department of Conservation and Economic Development
- Virginia Department of Highways
- Virginia Division of Mineral Resources

Washington:
- City of Port Angeles
- City of Seattle, Department of Lighting
- City of Tacoma:
  - Department of Public Utilities
  - Department of Public Works
- Clark County Public Utility District
- Coleville Business Council
- Cowlitz County Public Utility District
- Lummi Indian Business Council
- Muckleshoot Tribal Council
- Municipality of Metropolitan Seattle
- Nisqually Community Council
- Port of Seattle
- Skokomish Tribal Council
- The Evergreen State College
- Washington State, Department of Ecology
- Washington State, Department of Fisheries
- Washington State, Department of Game
- Washington State, Department of Highways
- Washington State, Department of Natural Resources, Division of Mines and Geology
- Yakima Tribal Council

West Virginia:
- Clarksburg Water Board
- Morgantown Water Commission
- West Virginia Department of Highways
- West Virginia Department of Natural Resources, Division of Water Resources
- West Virginia Geological and Economic Survey

Wisconsin:
- City of Madison
- The University of Wisconsin-Extension, Geological and Natural History Survey
- Southeastern Wisconsin Regional Planning Commission
- State Department of Natural Resources
- State Department of Transportation, Division of Highways

Wyoming:
- City of Cheyenne, Board of Public Utilities
- State Highway Commission of Wyoming
- Wyoming Department of Economic Planning and Development
- Wyoming Game and Fish Commission
- Wyoming Geological Survey
- Wyoming State Argiculture Commission
- Wyoming State Engineer

OTHER COOPERATORS AND CONTRIBUTORS

Government of American Samoa
Government of Guam

Virgin Islands:
- Caribbean Research Institute
- Department of Public Works

Permittees and licensees of Federal Power Commission

Puerto Rico:
- Puerto Rico Department of Public Works
- Puerto Rico Economic Development Administration, Industrial, Research Department
- Puerto Rico Environmental Quality Board
- Puerto Rico Mining Commission

Trust Territory of the Pacific Islands

U.S. GEOLOGICAL SURVEY OFFICES

MAIN CENTERS

Main Office: General Services Building, 18th and F Streets NW., Washington, D.C. 20242; 202 343-1100
Rocky Mountain Center: Federal Center, Denver, Colo. 80225; 303 234-3131
Pacific Coast Center: 345 Middlefield Road, Menlo Park, Calif. 94025; 415 323-8111

PUBLIC INQUIRIES OFFICES

Location	*Official in charge and telephone number*	*Address*
Alaska, Anchorage 99501	Margaret I. Erwin (907 277-0577)	Rm. 108, Skyline Bldg., 508 2d Ave.
California, Los Angeles 90012	Lucy E. Birdsall (213 688-2850)	Rm. 7638, Federal Bldg., 300 N. Los Angeles St.
San Francisco 94111	Jean V. Molleskog (415 556-5627)	Rm. 504, Custom House, 555 Battery St.
Colorado, Denver 80202	Lorene C. Young (303 837-4169)	Rm. 1012, Federal Bldg., 1961 Stout St.
Texas, Dallas 75202	Mary E. Reid (214 749-3230)	Rm. 1 C 45, 1100 Commerce St.
Utah, Salt Lake City 84111	Maurine Clifford (801 524-5652)	Rm. 8102, Federal Bldg., 125 S. State St.
Washington, Spokane 99201	Eva M. Raymond (509 456-2524)	Rm. 678, U.S. Court House, West 920 Riverside Ave.

SELECTED FIELD OFFICES IN THE UNITED STATES AND PUERTO RICO

[Temporary offices are not included, list current as of July 1, 1972. Correspondence to the following offices should be addressed to the Post Office Box, if one is given]

COMPUTER CENTER DIVISION

Location	*Official in charge and telephone number*	*Address*
Arizona, Flagstaff 86001	James E. Crawforth (602 774-8863)	601 E. Cedar Ave.
California, Menlo Park 94025	James L. Mueller (415 323-2661)	345 Middlefield Rd.
Colorado, Denver 80225	Frederick B. Sower (303 234-2551)	E2608, Bldg. 53, Federal Center.
Missouri, Rolla 65401	Glenn A. Ridgeway (314 364-6985)	P.O. Box 41.
South Dakota, Sioux Falls 57198	Gary I. Selner (605 336-2381)	EROS Data Center.

CONSERVATION DIVISION

[The small letter in parentheses following each official's name denotes branch affiliation in the Conservation Division as follows: c—Branch of Mineral Classification, m—Branch of Mining Operations, o—Branch of Oil and Gas Operations, w—Branch of Waterpower Classification]

Location	*Official in charge and telephone number*	*Address*
Alaska, Anchorage 99510	Alexander A. Wanek (c) (907 277-0570). Rodney A. Smith (o) (907 277-0579).	P.O. Box 259; 210—214 Skyline Bldg., 218 E St.
California, Los Angeles 90012	Keith A. Yenne (c) (213 688-2846). Donald W. Solanas (o) (213 688-2846).	Rm. 7744, Federal Bldg., 300 N. Los Angeles St.

Location	*Official in charge and telephone number*	*Address*
California--Continued		
Bakersfield 93301	Donald F. Russell (o) (805 323-7201)	Rm. 309, Federal Bldg., 800 Truxtun Ave.
Menlo Park 94025	Leo H. Saarela (m) (415 323-2563). Willard C. Gere (c) (415 323-2563).	345 Middlefield Rd.
Sacramento 95825	Kenneth W. Sax (w) (916 481-2219)	Rm. W-2231, Federal Bldg., 2800 Cottage Way.
Colorado, Denver 80202	John V. Finnegan (o) (303 837-4751). John P. Storrs (m) (303 837-4751). William C. Senkpiel (w) (303 837-4753). Robert G. Dickinson (c) (303 837-4752).	P.O. Box 3521; Rm. 6041, 6029, 6023, and 6025, Federal Bldg., 1961 Stout St.
Denver 80225	George H. Horn (c) (303 234-4435)	Bldg. 25, Federal Center.
Durango 81302	Jerry W. Long (o) (303 247-5144)	P.O. Box 1809; 3473 N. Main St.
Louisiana, Lafayette 70501	James O. Hinds (c), George Kinsel (o) (318 232-6037).	P.O. Box 52289; 239 Bendel Rd.
Metairie 70004	Robert F. Evans (o), Gayle A. Oglesby (c) (504 527-2424, 2333).	P.O. Box 546; 336 Imperial Office Bldg., 3301 N. Causeway Blvd.
Montana, Billings 59103	Albert F. Czarnowsky (m), Virgil L. Pauli (o) (406 245-6368); vacant (c) (406 245-6367).	P.O. Box 2550; 217 Post Office Bldg.
New Mexico, Artesia 88210	James A. Knauff (o) (505 746-4841)	Drawer U; 105 S. 4th St.
Carlsbad 88220	Robert S. Fulton (m) (505 885-6454). Larry Godwin (c) (505 885-9082).	P.O. Box 1716; Federal Bldg., 114 S. Halagueno St.
Farmington 87401	Philip T. McGrath (o), J. E. Fassett (c) (505 325-4572).	P.O. Box 959; Petroleum Club Plaza, 3535 E. 30th St.
Hobbs 88240	Arthur R. Brown (o) (505 393-3612).	Box 1157; 205 N. Linam St.
Roswell 88201	N. O. Frederick (o) (505 622-9857). Donald M. Van Sickle (c) (505 622-9857).	Drawer 1857; Federal Bldg. and U.S. Courthouse, Richardson Ave. at 5th St.
Oklahoma, McAlester 74501	Alexander M. Dinsmore (m) (918 423-5030).	P.O. Box 816; 509 S. 3d St.
Miami 74354	Claro V. Collins (m) (918 542-9481)	P.O. Box 509; Rm. 205, Federal Bldg.
Oklahoma City 73102	Charley W. Nease (o) (405 231-4011).	Rm. 4321, Federal Courthouse and Office Bldg., 220 NW. 4th St.
Tulsa 74103	Edward L. Johnson (c) (918 584-7638). Jess H. Hengst (o) (918 584-7151).	Rm. 4562 and 3413, New Federal Bldg., 333 W. 4th St.
Oregon, Portland 97208	Jesse L. Colbert (w) (503 234-4796).	P.O. Box 3202, 830 NE. Holladay St.
Utah, Salt Lake City 84111	Jackson W. Moffitt (m) (801 524-5646). Gerald R. Daniels (o) (801 524-5650). Howard F. Albee (c) (801 524-5643).	Rm. 8432, 8416, and 8422, Federal Bldg., 125 S. State St.
Washington, Tacoma 98401	Gordon C. Giles (w) (206 383-5830)	P.O. Box 1152; Rm. 244, Federal Bldg.
Wyoming, Casper 82601	Charles J. Curtis (o) (307 265-3405). Willis L. Rohrer (c) (307 265-3421).	P.O. Box 2859 and 2373; Rm. 2002 and 2001, Federal Bldg. and Post Office, 100 East B St.
Newcastle 82701	Glenn E. Worden (o) (307 746-2737)	P.O. Box 219; 214 W. Main St., Masonic Temple Bldg.
Rock Springs 82901	John A. Fraher (o) (307 362-6422). Arne A. Mattila (m) (307 362-7350).	P.O. Box 1170; Rm. 201 and 204, First Security Bank Bldg., 502 S. Front St.
Thermopolis 82443	Charles P. Clifford (o) (307 864-3477)	P.O. Box 590; Rm. 202, Federal Bldg.

GEOLOGIC DIVISION

OFFICES

Location	*Official in charge and telephone number*	*Address*
Alaska, Anchorage 99501	Donald H. Richter (907 272-8228)	216 Skyline Bldg., 218 E St.
College 99701	Florence R. Weber (907 479-7245)	P.O. Box 80586.
Arizona, Flagstaff 86001	John F. McCauley (602 774-5261, ext. 1455).	601 E. Cedar Ave.
	John D. Strobell (602 774-5261, ext. 1463).	
California, La Jolla 92037	George W. Moore (714 453-2820, ext. 341).	P.O. Box 271; 8604 La Jolla Shores Dr.
Hawaii, Hawaii National Park 96718	Donald W. Peterson (808 967-7485)	Hawaiian Volcano Observatory.
Kentucky, Lexington 40503	Wilds W. Olive (606 252-2552)	2035 Regency Rd.
Massachusetts, Boston 02110	Lincoln R. Page (617 223-7202)	80 Broad St.
Woods Hole 02543	John C. Behrendt (617 548-8533)	U.S. Geological Survey, Woods Hole Oceanographic Institution.
Ohio, Columbus 43210	James M. Schopf (614 421-2393)	Orton Hall, Ohio State Univ., 155 S. Oval Dr.
Puerto Rico, San Juan 00936	John M. Aaron (809 766-5340)	GPO Drawer 2230.
Santurce 00910	Dennis P. Cox (809 725-6550, ext. 259).	P.O. Box 8218; Departamento de Obras Públicas, Área de Recursos Naturales.
Tennessee, Knoxville 37902	Robert A. Laurence (615 524-4011, ext. 4268).	301 W. Cumberland Ave.
Texas, Austin 78701	D. Hoye Eargle (512 397-5959)	Rm. 801, Federal Bldg., 300 E. 8th St.
Corpus Christi 78411	Louis E. Garrison (512 883-5293)	P.O. Box 6732; Univ. of Corpus Christi.
Utah, Salt Lake City 84111	Lowell S. Hilpert (801 524-5640)	Rm. 8426, Federal Bldg., 125 S. State St.
Washington, Spokane 99201	Albert E. Weissenborn (509 456-4677).	West 920 Riverside Ave.
Wisconsin, Madison 53706	Carl E. Dutton (608 262-1234, ext. 1854).	222 Science Hall Univ. of Wisconsin.
Platteville 53818	Walter S. West (608 348-6486)	Wisconsin State Univ., Roundtree Hall.
Wyoming, Laramie 82070	J. David Love (307 745-4495)	Box 3007, Univ. Station, Geology Hall, Univ. of Wyoming.

RESPONSIBLE OFFICERS FOR INDIVIDUAL STATES

[Inquiries about Geologic Division programs should be directed to the appropriate officer listed below]

State	*Responsible officer and telephone number*	*Address*
Northeastern, Atlantic, and Southeastern States		
Connecticut, Massachusetts, and New Hampshire.	Lincoln R. Page (617 223-7202)	80 Broad St., Boston, Mass. 02110.
Alabama, Delaware, Florida, Maryland, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, Vermont, and Virginia.	Richard Goldsmith (301 344-2438).	Bldg. 420, Agricultural Research Center, Beltsville, Md. 20705.
Georgia, Maine, South Carolina, and Tennessee.	Frank G. Lesure (202 282-7144)	U.S. Geological Survey, Bldg. 10, Washington, D.C. 20242.
West Virginia	W. J. Mapel (303 234-3785)	Bldg. 25, Federal Center, Denver, Colo. 80225.

State	*Responsible officer and telephone number*	*Address*
	Mississippi Valley	
Arkansas, Illinois, Indiana, Iowa, Kentucky, Louisiana, Mississippi, Missouri, and Ohio.	Wilds W. Olive (606 252-2552)	2035 Regency Rd., Lexington, Ky. 40503.
Michigan, Minnesota, and Wisconsin	Frank G. Lesure (202 282-7144)	U.S. Geological Survey, Bldg. 10, Washington, D.C. 20242.
	North-Central, South-Central, and Rocky Mountains	
Colorado, Kansas, South Dakota, and Texas.	Raymond L. Parker (303 234-3830)	Bldg. 25, Federal Center, Denver, Colo. 80225.
Idaho, Nebraska, New Mexico, Montana, and Wyoming.	Edward T. Ruppel (303 234-2650)	Do.
Arizona, Nevada, and Utah	E. W. Tooker (415 323-2650)	345 Middlefield Rd., Menlo Park, Calif. 94025.
North Dakota and Oklahoma	W. J. Mapel (303 234-3785)	Bldg. 25, Federal Center Denver, Colo. 80225.
	Pacific States	
California	R. E. Wallace (415 323-2214)	345 Middlefield Rd., Menlo Park, Calif. 94025.
Oregon and Washington	Howard D. Gower (415 323-2353)	Do.
Alaska	George Gryc (415 323-2231)	Do.
Hawaii	Donald W. Peterson (808 967-7485)	Hawaiian Volcano Observatory, Hawaii National Park, Hawaii 96718.

TOPOGRAPHIC DIVISION

Location	*Engineer in charge and telephone number*	*Address*
California, Menlo Park 94025	Roy R. Mullen (415 323-2411)	345 Middlefield Rd.
Colorado, Denver 80225	Albert E. Letey (303 234-2351)	Bldg. 25, Federal Center.
Missouri, Rolla 65401	A. Carroll McCutchen (314 364-3680)	P.O. Box 133; 9th and Elm Sts.
Virginia, Arlington 22201	Peter F. Bermel (703 557-0927)	1109 N. Highland St.

WATER RESOURCES DIVISION

REGIONAL OFFICES

Location	*Official in charge and telephone number*	*Address*
Atlantic Coast Region: Arlington, Va. 22209	George E. Ferguson, Regional Hydrologist (202 343-8841).	Rm. 317, George Washington Bldg., Arlington Towers, 1011 Arlington Blvd.
Midcontinent Region: St. Louis, Mo. 63141	Rex R. Meyer, acting Regional Hydrologist (314 268-7224).	Suite 212, 2222 Schuetz Rd.
Rocky Mountain Region: Denver, Colo. 80225	Thad G. McLaughlin, Regional Hydrologist (303 234-3661).	Bldg. 25, Federal Center.
Pacific Coast Region: Menlo Park, Calif. 94025	Elwood R. Leeson, Regional Hydrologist (415 323-8111, ext. 2337, 2338, 2339, 2487).	345 Middlefield Rd.

DISTRICT OFFICES

Location	*Official in charge and telephone number*	*Address*
Alabama, Tuscaloosa 35486	William L. Broadhurst (205 752-8104).	P.O. Box V; Rm. 202, Oil and Gas Board, Univ. of Alabama.
Alaska, Anchorage 99501	Harry Hulsing (907 277-5526, 5527) .	Skyline Bldg., 218 E St.
Arizona, Tucson 85717	Horace M. Babcock (602 792-6391, 6395).	P.O. Box 4070, 2555 E. First St.
Arkansas, Little Rock 77201	Richard T. Sniegocki (501 378-5246) .	Rm. 2301, Federal Office Bldg., 700 W. Capitol Ave.
California, Menlo Park 94025	Lee R. Peterson, acting (415 323-8111, ext. 2326, 2327, 2465, 2466).	855 Oak Grove Ave.
Colorado, Denver 80225	Edward A. Moulder (303 234-3815) .	Bldg. 25, Federal Center.
Connecticut, Hartford 06101	John A. Baker (203 244-2528)	P.O. Box 715; Rm. 235, Post Office Bldg., 135 High St.
Delaware	Walter F. White, Jr. (301 661-4664) .	See Maryland District Office.
District of Columbia	do	Do.
Florida, Tallahassee 32304	Clyde S. Conover (904 224-1202, 1203).	903 W. Tennessee St.
Georgia, Atlanta 30309	John R. George (404 526-3981)	Rm. 301, 900 Peachtree St., N.E.
Hawaii, Honolulu 96814	Willis L. Burnham (808 546-5692, 5693, 5694, 5695).	Rm. 330, First Insurance Bldg., 1100 Ward Ave.
Idaho, Boise 83702	Hal K. Hall (208 342-2711, ext. 538) .	P.O. Box 036, FBUSCH; Rm. 365, Federal Bldg. and U.S. Courthouse, 550 W. Fort St.
Illinois, Champaign 61820	Davis W. Ellis (217 359-3918)	P.O. Box 1026; 605 N. Neil St.
Indiana, Indianapolis 46202	James L. Cook (317 633-7398)	1819 North Meridian St.
Iowa, Iowa City 52240	Sulo W. Wiitala (319 338-0581, ext. 475).	Suite F, 1041 Arthur St.
Kansas, Lawrence 66044	Charles W. Lane (913 864-4321)	1950 Avenue "A"—Campus West, Univ. of Kansas.
Kentucky, Louisville 40202	Robert V. Cushman (502 582-5241, 5242, 5243).	Rm. 572, Federal Bldg., 600 Federal Place.
Louisiana, Baton Rouge 70806	Albert N. Cameron (504 348-0181, ext. 281).	Rm. 215, Prudential Bldg., 6554 Florida Blvd.
Maine, Augusta 04330	Gordon S. Hayes (207 289-3484)	State House Annex, Capitol Shopping Center.
Maryland, Parkville 21234	Walter F. White, Jr. (301 661-4664) .	8809 Satyr Hill Rd.
Massachusetts, Boston 02203	Charles E. Knox (617 223-2822)	Rm. 2300, John F. Kennedy Federal Bldg.
Michigan, Lansing 48933	Timmy R. Cummings (517 372-1561) .	Rm. 700, Capitol Savings and Loan Bldg., 112 E. Allegan St.
Minnesota, St. Paul 55101	Charles R. Collier (612 725-7841, 7842).	Rm. 1033, Post Office Bldg.
Mississippi, Jackson 39206	Lamar E. Carroon (601 948-7821, ext. 326).	430 Bounds St.
Missouri, Rolla 65401	Anthony Homyk, Jr. (314 364-1599) .	P.O. Box 340; 103 W. 10th St.
Montana, Helena 59601	George M. Pike (406 442-9040, ext. 3263).	P.O. Box 1696; Rm. 421, Federal Bldg., 316 N. Park Ave.
Nebraska, Lincoln 68508	Kenneth A. MacKichan (402 475-3643).	Rm. 127, Nebraska Hall 901 N. 17th St.
Nevada, Carson City 89701	George F. Worts, Jr. (702 882-1388) .	Rm. 229, Federal Bldg. 705 N. Plaza St.
New Hampshire	Charles E. Knox (617 223-2822)	See Massachusetts District Office.
New Jersey, Trenton 08607	John E. McCall (609 599-3511, ext. 212, 213).	P.O. Box 1238; Rm. 420, Federal Bldg. 402 East State St.
New Mexico, Albuquerque 87106	William E. Hale (505 843-2246)	P.O. Box 4369; Geology Bldg., Univ. of New Mexico.
New York, Albany 12201	Robert J. Dingman (518 472-3107) ..	P.O. Box 948; Rm 343, U.S. Post Office and Custom House.
North Carolina, Raleigh 27602	Ralph C. Heath (919 755-4510)	P.O. Box 2857; Rm. 440, Century Sta. Post Office Bldg.

Location	*Official in charge and telephone number*	*Address*
North Dakota, Bismarck 58501	Robert C. Williams (701 255-4011, ext. 227, 228).	P.O. Box 778; Rm. 348, New Federal Bldg., 3d St. and Rosser Ave.
Ohio, Columbus 43212	John J. Molloy (614 469-5553, 5554).	975 W. 3d Ave.
Oklahoma, Oklahoma City 73102	James H. Irwin (405 231-4256)	Rm. 4301, Federal Bldg. and U.S. Court House, 200 NW. 4th St.
Oregon, Portland 97208	Stanley F. Kapustka (503 234-3361, ext. 4776, 4777, 4778).	P.O. Box 3202; 830 NE. Holladay St.
Pennsylvania, Harrisburg 17108	Norman H. Beamer (717 782-3468)	P.O. Box 1107; 4th Floor, Federal Bldg., 228 Walnut St.
Puerto Rico, San Juan 00934	Donald G. Jordan (809 783-4660, 4469, 4788).	Bldg. 652, Fort Buchanan.
Rhode Island	Charles E. Knox (617 223-2822)	See Massachusetts District Office.
South Carolina, Columbia 29204	John S. Stallings (803 252-3751)	2001 Assembly St., Suite 200.
South Dakota, Huron 57350	John E. Powell (605 352-8651, ext. 293, 294).	P.O. Box 1412; Rm. 231, Federal Bldg.
Tennessee, Nashville 37203	Harry H. Barnes, Jr. (615 749-5424)	Rm. 144, Federal Bldg.
Texas, Austin 78701	I. Dale Yost (512 397-5766)	Rm. 630, Federal Bldg., 300 E. 8th St.
Utah, Salt Lake City 84111	Theodore Arnow (801 524-5663)	Rm. 8002, Federal Bldg., 125 S. State St.
Vermont	Charles E. Knox (617 223-2822)	See Massachusetts District Office.
Virginia, Richmond 23220	James W. Gambrell (703 782-2427)	Rm. 304, 200 W. Grace St.
Washington, Tacoma 98402	Leslie B. Laird (206 383-2861, ext. 384).	Rm. 300, 1305 Tacoma Ave., South.
West Virginia, Charleston 25301	Edwin E. Harris (304 343-6181, ext. 310, 311).	Rm. 3303, Federal Bldg. and U.S. Court House, 500 Quarrier St., East.
Wisconsin, Madison 53706	Charles L. R. Holt, Jr. (608 262-2488).	Rm. 200, 1815 University Ave.
Wyoming, Cheyenne 82001	Robert L. Cushman (307 778-2220, ext. 2111).	P.O. Box 2087; 2d Floor, Blue Cross Bldg., 215 E. 8th Ave.

OFFICES IN OTHER COUNTRIES

GEOLOGIC DIVISION

Location	*Official in charge*	*Address*
Brazil, Rio de Janerio	Max G.White	U.S. Geological Survey, USAID/Rio de Janerio/ENGR, APO New York 09676.
Salvador	do	U.S. Geological Survey, c/o American Consulate, USAID/USGS/Salvador, APO New York 09676.
Colombia, Bogota	Earl M. Irving	U.S. Geological Survey, USAID, c/o American Embassy, APO New York 09895.
Indonesia, Bandung	Paul W. Richards	U.S. Geological Survey, c/o American Embassy, USAID/ENGR, APO San Francisco 96356.
Liberia, Monrovia	Alfred H. Chidester	U.S. Geological Survey, c/o American Embassy, AID/Geology, APO New York 09155.
Saudi Arabia, Jiddah	Thor H. Kiilsgaard	U.S. Geological Survey, c/o American Embassy, APO New York 09697.

WATER RESOURCES DIVISION

Location	*Official in charge*	*Address*
Brazil, Rio de Janerio	Woodrow W. Evett	U.S. AID Rio/ENRN/USGS, APO New York 09676.
Ethiopia, Addis Ababa	Harold E. Gill	U.S. AID, APO New York 09319.
Kenya, Nairobi	Wolfgang V. Swarzenski	U.S. AID/Nairobi, U.S. Dept. of State Washington, D.C. 20521.
Nepal, Katmandu	G. Chase Tibbitts, Jr.	U.S. Geological Survey, USAID/Katmandu (ID), U.S. Dept. of State, Washington, D.C. 20521.
Pakistan, Lahore	Paul R. Seaber	U.S. Geological Survey, USAID/Lahore, U.S. Dept. of State, Washington, D.C. 20521.
India, Bangalore	Neal E. McClymonds	U.S. Geological Survey, USAID/Bangalore, U.S. Dept. of State, Washington, D.C. 20521.
New Delhi	James R. Jones	U.S. Geological Survey, USAID/New Delhi, U.S. Dept. of State, Washington, D.C. 20521.

INVESTIGATIONS IN PROGRESS IN THE CONSERVATION, GEOLOGIC, AND WATER RESOURCES DIVISIONS

Investigations in progress during fiscal year 1972 are listed below, together with the names and headquarters of the individuals in charge of each. Headquarters at main centers are indicated by (W) for Washington, D.C., (D) for Denver, Colo., and (M) for Menlo Park, Calif.; headquarters in other cities are indicated by name (see list of offices, p. A253, for addresses). Inquiries regarding projects for which no address is given in the list of offices should be directed to the appropriate Division of the Geological Survey, Washington, D.C., 20242. The lowercase letter after the name of the project leader shows the Division technical responsibility: c, Conservation Division; w, Water Resources Division; no letter, Geologic Division.

The projects are classified by principal topic. Most geologic-mapping projects involve special studies of stratigraphy, petrology, geologic structure, or mineral deposits, but are listed only under "Geologic Mapping" unless a special topic or commodity is the primary justification for the project. A reader interested in investigations of volcanology, for example, should look under the heading "Geologic Mapping" for projects in areas of volcanic rocks, as well as under the heading "Volcanology." Likewise, most water-resources investigations involve special studies of several aspects of hydrology and geology, but are listed only under "Water Resources" unless a special topic—such as floods or sedimentation—is the primary justification for the project.

Areal geologic mapping is subdivided into mapping at scales smaller than 1 inch to 1 mile (for example, 1:250,000), and mapping at scales of 1 inch to 1 mile, or larger (for example, 1:62,500; 1:24,000).

Abstracts. *See* Bibliographies and abstracts.

Analytical chemistry:
- Activation analysis (J. Rowe, W)
- Analytical methods—water chemistry (M. W. Skougstad, w, D)
- Analytical services and research (J. I. Dinnin, W; C. Huffman, Jr., D; C. O. Ingamells, M)
- Hydrologic applications:
  - Identification and behavior of organic materials in water (M. C. Goldberg, w, D)
  - Organic geochemistry (R. L. Malcolm, w, D)
- Instrumentation (J. F. Abell, W)
- Mineral deposits, characteristic analysis (J. M. Botbol, D)
- Natural organic, macromolecules in water (R. L. Wershaw, w, D)
- Organic geochemistry and infrared analysis (I. A. Breger, W)
- Organic substances in water (D. F. Goerlitz, w, M)
- Pesticides, determination in water (C. G. Angelo, w, Columbus, Ohio)
- Puerto Rico laboratory, training and technical aid (A. P Marranzino, D)
- Radioactivation and radiochemistry (H. T. Millard, D)
- Radiometric methods of analysis (L. L. Tatcher, w, D)
- Rock chemical analysis:
  - General (L. C. Peck, D)
  - Rapid (L. Shapiro, W)
- Sample control (H. Bastron, M)
- Services (J. L. Ramisch, W; L. B. Riley, D)
- Spectrochemistry (E. L. Mosier, D)
- Trace analysis methods, research (F. N. Ward, D)
- Ultratrace analysis (H. T. Millard, D)
- Water analysis, quality control (E. Brown, w, D)
- *See also* Spectroscopy.

Arctic engineering geology (R. Kachadoorian, M)

Artificial recharge:
- Artificial recharge of fractured carbonate rocks (H. O. Reeder, w, St. Paul, Minn.)

Artificial recharge--Continued
- Florida:
  - Artificial recharge study, eastern Orange County (D. D. Knochenmus, w, Ocala)
  - Deep well waste injection, Dade County (F. W. Meyer, w, Miami)
  - Floridan aquifer, Peace-Alafia (R. W. Coble, w, Tampa)
  - Floridan aquifer, west-central area (W. C. Sinclair, w, Tampa)
  - Injection of wastes in deep wells (C. W. Pascale, w, Tallahassee)
  - Subsurface waste storage, Pinellas County (R. N. Cherry, w, Tampa)
  - Subsurface waste storage, statewide (M. I. Kaufman, w, Tallahassee)
- Kansas:
  - Artificial recharge in western Kansas (J. B. Gillespie, w, Lawrence)
- New York:
  - Prediction of movement in zone of aeration, Long Island, (R. C. Prill, w, Mineola)
  - Treated sewage through an injection well, Bay Park, Long Island (J. Vecchioli, w, Mineola)

Asbestos:
- Southeastern United States, ultramafic rocks (D. M. Larrabee, W)

Barite:
- Geology, geochemistry, and resources of barite (D. A. Brobst, D)

Base metals:
- Missouri, iron (P. W. Guild, W)
- *See also base-metal names.*

Bibliographies and abstracts:
- Geophysical abstracts (J. W. Clarke, W)
- Lunar bibliography (J. H. Freeberg, M)
- North American geology, bibliography (J. W. Clarke, W)

Bibliographies and abstracts--Continued
Urban hydrology—A selected bibliography with abstracts (G. L. Knapp, J. P. Glasby, w, W)
Vanadium, geology and resources, bibliography (J. P. Ohl, D)
Water-resources selected abstracts, bibliography, index, input to Water Resources Scientific Information Center (J. W. Lang, w, W)
Borates:
California:
Furnace Creek area (J. F. McAllister, M)
Searles Lake area (G. I. Smith, M)
Chromite. *See* Ferro-alloy metals.
Clays:
Appalachia, northern part (J. W. Hosterman, Beltsville, Md.)
Florida and Georgia, Attapulgus-Thomasville fuller's earth deposits (S. H. Patterson, Beltsville, Md.)
Coal:
Resources of the United States (P. Averitt, D)
Alaska:
Bering River coal field (A. A. Wanek, c, Anchorage)
Cape Beaufort-Corwin Bluff coal field (A. A. Wanek, c, Anchorage)
Kukpowruk River coal field (A. A. Wanek, c, Anchorage)
Nenana (C. Wahrhaftig, M)
Arizona:
Cummings Mesa quadrangle (F. Peterson, c, D)
Gunsight Butte SW quadrangle (F. Peterson, c, D)
Colorado:
Buckhorn Lakes quadrangle (R. G. Dickinson, c, D)
Citadel Plateau (G. A. Izett, c, D)
Courthouse Mountain quadrangle (R. G. Dickinson, c, D)
Denver basin, Tertiary coal zone (P. E. Soister, c, D)
Disappointment Valley, eastern (D. E. Ward, D)
Kremmling quadrangle (G. A. Izett, c, D)
Middle Park—North Park area (G. A. Izett, c, D)
Rangely NE quadrangle (H. L. Cullins, c, Metairie, La.)
Savery quadrangle (C. S. V. Barclay, c, D)
Strasburg NW and SW quadrangles (P. E. Soister, c, D)
Washboard Rock quadrangle (R. G. Dickinson, c, D)
Watkins and Watkins SE quadrangles (P. E. Soister, c, D)
Montana:
Decker quadrangle (B. E. Law, c, Casper, Wyo.)
Hardy quadrangle (K. S. Soward, c, Casper, Wyo.)
Jordan quadrangle (G. D. Mowat, c, Billings)
Monarch quadrangle (B. E. Barnum, c, D)
Pearl School quadrangle, (F. N. Murray, c, Casper, Wyo.)
Ranchester quadrangle, (B. E. Barnum, c, D)
Rocky Reef quadrangle (K. S. Soward, c, Casper, Wyo.)
New Mexico:
Fruitland Formation (J. E. Fassett, c, Farmington)
Gallup West quadrangle (J. E. Fassett, c, Farmington)
Manuelito quadrangle (J. E. Fassett, c, Farmington)
Samson Lake quadrangle (J. E. Fassett, c, Farmington)
Twin Butte quadrangle (J. E. Fassett, c, Farmington)
Western Raton field (C. L. Pillmore, D)
North Dakota:
Clark Butte 15-minute quadrangle (G. D. Mowat, c, Billings, Mont.)
Dengate quadrangle (C. S. V. Barclay, c, D)
Glen Ullin quadrangle (C. S. V. Barclay, c, D)
Heart Butte and Heart Butte NW quadrangles (E. V. Stephens, c, M)
New Salem quadrangle (H. L. Smith, c, D)
Coal--Continued
North Dakota--Continued
North Almont quadrangle (H. L. Smith, c, D)
White Butte 15-minute quadrangle (K. S. Soward, c, Casper, Wyo.)
Pennsylvania:
Anthracite region, flood control (M. J. Bergin, W)
Claysville-Avella area (S. P. Schweinfurth, W)
Mather-Garards Fort area (B. H. Kent, D)
Southern anthracite field (G. H. Wood, Jr., W)
Waynesburg-Oak Forest area (J. B. Roen, Beltsville, Md.)
Western Middle anthracite field (H. Arndt, D)
Utah:
Basin Canyon quadrangle (F. Peterson, c, D)
Big Hollow Wash quadrangle (F. Peterson, c, D)
Blackburn Canyon quadrangle (F. Peterson, c, D)
Butler Valley quadrangle, (W. E. Bowers, c, D)
Canaan Creek quadrangle (H. D. Zeller, c, D)
Canaan Peak quadrangle (W. E. Bowers, c, D)
Carcass Canyon quadrangle (H. D. Zeller, c, D)
Collet Top quadrangle (H. D. Zeller, c, D)
Cummings Mesa quadrangle (F. Peterson, c, D)
Dave Canyon quadrangle (H. D. Zeller, c, D)
Death Ridge quadrangle (H. D. Zeller, c, D)
East-of-the-Navajo quadrangle (F. Peterson, c, D)
Fourmile Bench quadrangle (W. E. Bowers, c, D)
Griffin Point quadrangle (W. E. Bowers, c, D)
Gunsight Butte SW¼ quadrangle (F. Peterson, c, D)
Henrieville quadrangle (W. E. Bowers, c, D)
Horse Mountain quadrangle (W. E. Bowers, c, D)
Jessen Butte quadrangle (E. M. Schell, c, Casper, Wyo.)
Needle Eye Point quadrangle (H. D. Zeller, c, D)
Pete's Cove quadrangle (H. D. Zeller, c, D)
Pine Lake quadrangle (W. E. Bowers, c, D)
Seep Flat quadrangle (E. V. Stephens, c, D)
Ship Mountain Point quadrangle (H. D. Zeller, c, D)
Sooner Bench quadrangle (F. Peterson, c, D)
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Upper Valley quadrangle (W. E. Bowers, c, D)
Wide Hollow Reservoir (E. V. Stephens, c, M)
Virginia, Pocahontas coal beds (K. J. Englund, W)
Wyoming:
Alpine quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Bailey Lake quadrangle (M. L. Schroeder, c, D)
Browns Hill quadrangle (C. S. V. Barclay, c, D)
Bull Creek quadrangle (M. L. Schroeder, c, D)
Cache Creek quadrangle (D. A. Jobin, c, D)
Cottonwood Rim quadrangle (C. S. V. Barclay, c, D)
Creston Junction quadrangle (R. B. Sanders, c, D)
Deer Creek quadrangle (D. A. Jobin, c, D)
Ferry Peak quadrangle (D. A. Jobin, c, D)
Gillette Coal Field (W. L. Rohrer, c, Casper)
Grieve Reservoir quadrangle (C. S. V. Barclay, c, D)
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Monarch quadrangle (B. E. Barnum, c, D)
Observation Peak quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Oil Mountain quadrangle (W. H. Laraway, c, Casper)
Pickle Pass quadrangle (D. A. Jobin, c, D)
Poison Spider quadrangle (W. H. Laraway, c, Casper)
Ranchester quadrangle (B. E. Barnum, c, D)
Reid Canyon (W. H. Laraway, c, Casper)
Riner quadrangle (R. B. Sanders, c, D)

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Wyoming--Continued
Savery quadrangle (C. S. V. Barclay, c, D)
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Ship Mountain Point quadrangle (H. D. Zeller, c, D)
Square Top Butte quadrangle (W. H. Laraway, c, Casper)
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Construction and terrain problems:
Deformation research (S. P. Kanizay, D)
Electronics instrumentation research (J. B. Bennetti, D)
Engineering properties of rocks and soils (T. C. Nichols, Jr., D)
Geologic environmental studies for land-use planning, California (C. M. Wentworth, Jr., M)
Geologic factors in coal-mine roof-falls, Pennsylvania and West Virginia (B. H. Kent, D)
Mudflow studies, Washington, Oregon, and Colorado (D. R. Crandell, D)
Source materials services (L. D. Bonham, W)
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USSR terrain (J. Rachlin, W)
Alaska:
Arctic engineering (G. Gryc, M)
Geologic investigations, Amchitka Island (L. M. Gard, Jr., D)
Marine terrace study, Aleutian Islands (R. H. Morris, D)
California:
Los Angeles (J. T. McGill, D)
Regional slope stability studies (D. H. Radbruch, M)
San Francisco Bay sediments, engineering geology studies (D. R. Nichols and J. Schlocker, M)
Massachusetts, sea-cliff erosion studies (C. A. Kaye, Boston)
Nevada:
Engineering geophysics, Nevada Test Site (R. D. Carroll, D)
Geologic investigations, Nevada Test Site (P. P. Orkild, D)
Geomechanical investigations, Nevada Test Site (J. R. Ege, D)
Utah, coal-mine bumps (F. W. Osterwald, D)
See also Urban geology.
Contamination, water:
Distribution, source, and transport of organic pesticides in reservoir sediments (M. L. Yates, w, W)
Pesticide pollutants in water (R. L. Wershaw, w, D)
Arizona, environmental monitoring of Black Mesa coal development (E. H. McGavock, w, Flagstaff)
Massachusetts, ground-water contamination from highway salt (L. G. Toler, w, Boston)
New Hampshire, ground-water contamination from highway salt (C. E. Hale, w, Concord)
New York:
Long Island, Suffolk County, effect of solid-waste disposal sites on ground-water quality (G. E. Kimmel, w, Mineola)
Long Island, Suffolk County, geochemical aspects of pollution, Babylon-Islip (J. Soren, w, Mineola)
See also Analytical chemistry; Salt-water intrusion.
Copper:
Arizona, Ray porphyry copper (H. R. Cornwall, M)
Maine and New Hampshire, porphyry, with molybdenum (R. G. Schmidt, W)
Copper--Continued
Michigan:
Greenland and Rockland quadrangles (J. W. Whitlow, Beltsville, Md.)
Michigan copper district (W. S. White, Beltsville, Md.)
Nevada, Copper Canyon deposit (T. G. Theodore, M)
Puerto Rico (D. P. Cox, Santurce)
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Crustal studies:
Tectonic studies (W. B. Hamilton, D)
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Earthquake studies:
Aftershock studies (R. L. Wesson, M)
Contemporary coastal deformation (R. O. Castle, M)
Crustal strain (J. C. Savage, M)
Crustal studies (ARPA) (I. Zietz, W)
Earth structure studies (J. H. Healy, M)
Fault-zone geophysical studies (W. H. Jackson, M)
Fault-zone tectonics (J. C. Savage, M)
Fluid injection, laboratory investigations (J. D. Byerlee, L. Peselnick, M)
Ground motion studies (J. H. Healy, M)
Hazard analysis:
Anchorage, Alaska (E. Dobrovolny, D)
Juneau, Alaska (R. D. Miller, D)
Small coastal communities (R. W. Lemke, D)
Portable seismic arrays (W. H. Jackson, M)
Relative activity of multiple fault strands (M. G. Bonilla, M)
Research on rock mechanics (T. C. Nichols, Jr., D)
Seismic source studies (W. R. Thatcher, M)
Stress studies (C. B. Raleigh, M)
Alaska, seismic and strain studies—TAPS (R. A. Page, M)
California:
Basement and volcanic rock studies along San Andreas fault (D. C. Ross, M)
Breaks along San Andreas fault (M. M. Clark, M)
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Geologic framework of San Andreas fault (H. D. Gower, M)
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Microearthquake net (R. L. Wesson, M)
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Colorado, Rangely (C. B. Raleigh, M)
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Ecology:
Effects of small impoundments on the interrelation between aquatic biota and chemical quality of Nederlo Creek (P. A. Kammerer, w, Madison, Wis.)
California, benthos, artificial substrates evaluation (R. C. Averett, w, M)
Washington, influence of stream hydraulics on anadromous fish migration and propagation (M. R. Collings, w, Tacoma)
Engineering geologic studies. *See* Construction and terrain problems; Urban geology.
Evaporation:
Evaporation from lakes and reservoirs (A. M. Sturrock, Jr. w, D)

Evaporation--Continued
- California, verification of mass-transfer and pan relations for large lakes and reservoirs, Salton Sea (A. M. Sturrock, Jr., w, D)
- Indiana, evaporation losses from lakes (J. E. Heisel, w, Indianapolis)
- North Carolina:
  - Hyco Lake, evaporation and thermal loading analysis (W. L. Yonts, w, Raleigh)
  - Lake Michie, evaporation analysis (W. L. Yonts, w, Raleigh)
- *See also* Hydrologic instrumentation.

Evaporation suppression:
- Mechanics of evaporation suppression and evaporation (G. E. Koberg, w, D)

Evapotranspiration:
- Collection of data on evapotranspiration and variables controlling it (T. E. A. van Hylckama, w, Lubbock, Tex.)
- Hydrologic effects of vegetation modification (R. M. Myrick, w, Tucson, Ariz.)
- Use of water by saltcedar in evapotranspirometers, measured and computed by energy budget and mass transfer methods, Arizona (T. E. A. van Hylckama, w, Lubbock, Tex.)
- Arizona:
  - Phreatophyte project, Gila River (R. C. Culler, w, Tucson)
  - Study of effects of vegetation manipulation on surface runoff, Sycamore Creek (H. W. Hjalmarson, w, Phoenix)
- California, root-zone conditions and plant-physiological processes as factors in phreatophyte evapotranspiration (O. M. Grosz, w, M)

Extraterrestrial studies:
- Lunar and planetary analog studies:
  - Deep seated inclusions (H. G. Wilshire, M)
  - Experimental impact investigations (H. J. Moore, M)
  - Explosion craters (D. J. Roddy, Flagstaff, Ariz.)
  - Fort Rock crater (G. S. Fuis, Pasadena, Calif.)
  - Impact metamorphism (E. C. T. Chao, W)
  - Peruvian coastal desert (E. C. Morris, Flagstaff, Ariz.)
  - Shock phase studies (O. B. James, W)
- Lunar data synthesis:
  - Apollo 15-17 photogeology (H. J. Moore, M)
  - Apollo 17 electromagnetic sounder (R. E. Eggleton, Flagstaff, Ariz.)
  - Apollo orbital science data (H. Masursky, Flagstaff, Ariz.)
  - Lunar metric studies (S. Wu, Flagstaff, Ariz.)
  - Lunar morphologic studies (R. J. Pike, Jr., M)
- Lunar field geology:
  - Apollo 11-15 (G. A. Swann, Flagstaff, Ariz.)
  - Apollo 16, 17 (W. A. Muehlberger, Austin, Tex.)
- Lunar mapping:
  - Apollo landing sites (D. H. Scott, Flagstaff, Ariz.)
  - Far side, center (D. E. Stuart-Alexander, M)
  - Far side, east limb (D. E. Wilhelms, M)
  - Far side, west limb (D. H. Scott, Flagstaff, Ariz.)
  - Large scale science sites (M. N. West, Flagstaff, Ariz.)
  - North Pole (B. Lucchitta, Flagstaff, Ariz.)
  - South Pole (K. A. Howard, M)
  - Volcanic provinces (L. A. Soderblom, Flagstaff, Ariz.)
- Lunar sample investigations:
  - Chemical and X-ray fluorescence analysis (H. J. Rose, Jr., W)

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- Lunar sample investigations--Continued
  - Feldspars (D. E. Appleman, W)
  - Glass, magnetic properties (F. E. Sentfle, W)
  - Impact metamorphism (E. C. T. Chao, W)
  - Isotopic composition of uranium, thorium, and protactinium (J. N. Rosholt, D)
  - Mass spectrometry (M. Tatsumoto, D)
  - Oxygen fugacities and crystallization sequence (M. Sato, W)
  - Particulate debris (M. H. Carr, M)
  - Petrographic identification (H. G. Wilshire, M)
  - Petrographic, mineralogic, and size-frequency analysis (G. A. Sellers, W)
  - Petrologic studies (E. Roedder, W)
  - Pyroxenes (M. Ross, W)
  - Specific heats (R. A. Robie, W)
  - Water contents, deuterium, C^{13} and O^{18} analysis (I. Friedman, D)
- Planetary investigations:
  - Geologic mapping of Mars (D. H. Scott, J. F. McCauley, Flagstaff, Ariz.)
  - Mariner Mars 1971 TV (H. Masursky, Flagstaff, Ariz.)
  - Mariner Venus-Mercury TV (N. J. Trask, W)
  - Mars cartography (R. M. Batson, Flagstaff, Ariz.)
  - Planetary remote sensing (L. C. Rowan, D)
  - Radar applications (G. G. Schaber, Flagstaff, Ariz.)
  - Viking lander (E. C. Morris, Flagstaff, Ariz.)
  - Viking orbiter TV (M. H. Carr, M)
  - Viking—physical properties of Mars (H. J. Moore, M)

Ferro-alloy metals:
- Chromium resource studies (T. P. Thayer, W)
- Manganese, zoning in epithermal deposits (R. G. Worl, D)
- Molybdenum, Maine and New Hampshire, with porphyry copper (R. G. Schmidt, W)
- Molybdenum-rhenium resource studies (R. U. King, D)
- Tungsten, North Carolina, Hamme district (J. E. Gair, W)
- Ultramafic rocks of the Southeastern United States (D. M. Larrabee, W)
- Montana, chromite resources and petrology, Stillwater complex (E. D. Jackson, M)
- Oregon, John Day area (T. P. Thayer, W)

Flood characteristics of streams at selected sites:
- Alabama, flood studies and bridge-site investigations (C. O. Ming, w, Tuscaloosa)
- Alaska, flood insurance studies (R. D. Lamke, w, Anchorage)
- Florida, bridge-site investigations statewide (W. C. Bridges, w, Tallahassee)
- Georgia, bridge-site investigations (M. Price, w, Atlanta)
- Iowa, flood information at selected bridge sites (O. G. Lara, w, Iowa City)
- Kentucky, bridge-site investigations (C. H. Hannum, w, Louisville)
- Mississippi, bridge-site flood investigations (C. H. Tate, w, Jackson)
- Montana, bridge-site investigations (M. V. Johnson, R. J. Omang, w, Helena)
- Nebraska (E. W. Beckman, w, Lincoln)
- New Mexico, peak flood-flow characteristics of small streams (A. G. Scott, w, Santa Fe)
- North Dakota (O. A. Crosby, w, Bismarck)
- Ohio (R. I. Mayo, w, Columbus)
- Oregon, flood profiles, Umpqua River and tributaries (D. D. Harris, w, Portland)

Flood characteristics of streams at selected sites--Continued
South Carolina (B. H. Whetstone, w, Columbia)
Tennessee (W. J. Randolph, w, Nashville)
Utah, cloudburst floods in Utah 1939-70 (E. Butler, w, Salt Lake City)
West Virginia (P. M. Frye, w, Charleston)
Wyoming, flood studies and bridge-site investigations (S. A. Druse and D. J. O'Connell, w, Cheyenne).

Flood discharge from small drainage areas:
Colorado (G. L. Ducret, Jr., w, D)
Connecticut (M. P. Thomas, w, Hartford)
Delaware (R. H. Simmons, w, Dover)
Florida (W. C. Bridges, w, Tallahassee)
Georgia (H. G. Golden, w, Atlanta)
Idaho (C. A. Thomas, w, Boise)
Illinois (J. D. Camp, w, Champaign)
Iowa (O. G. Lara, w, Iowa City)
Kansas (H. R. Hejl, w, Lawrence)
Maine (R. A. Morrill, w, Augusta)
Maryland (D. H. Carpenter, w, College Park)
Massachusetts (C. G. Johnson, Jr., w, Boston)
Minnesota (L. C. Guetzkow, w, St. Paul)
Mississippi (J. W. Hudson, w, Jackson)
Montana (M. V. Johnson, R. J. Omang, w, Helena)
Nebraska (E. W. Beckman, w, Lincoln)
New Jersey (S. J. Stankowski, w, Trenton)
North Dakota (O. A. Crosby, w, Bismarck)
Ohio (E. E. Webber, w, Columbus)
Oregon (J. Friday, w, Portland)
Rhode Island (C. G. Johnson, Jr., w, Boston, Mass.)
South Carolina (B. H. Whetstone, w, Columbia)
South Dakota (L. D. Becker, w, Huron)
Tennessee, statewide (H. C. Wibben, w, Nashville)
Texas (E. E. Schroeder, w, Austin)
Vermont (C. G. Johnson, Jr., w, Boston, Mass.)
Virginia (E. M. Miller, w, Richmond)

Flood frequency:
Alabama, flood frequency synthesis for small streams (J. F. McCain, w, Tuscaloosa)
Colorado, Denver metropolitan area (G. L. Ducret, Jr., w, D)
Georgia (M. Price, w, Atlanta)
Illinois (J. D. Camp, w, Champaign)
Iowa (O. G. Lara, w, Iowa City)
Kansas (P. R. Jordan, w, Lawrence)
Kentucky, magnitude and frequency (C. H. Hannum, w, Louisville)
Louisiana:
Flood frequency of small areas (L. A. Martens, w, Baton Rouge)
Hydrology and hydraulics for highways (B. L. Neely, w, Baton Rouge)
New Jersey, magnitude and frequency and effect of basin characteristics (S. J. Stankowski, w, Trenton)
North Carolina, flood frequency and high-flow studies (H. G. Hinson, w, Raleigh)
Tennessee, magnitude and frequency of floods on small streams (H. C. Wibben, w, Nashville)
Utah, magnitude and flood frequency (F. K. Fields, w, Salt Lake City)
Wisconsin, magnitude and frequency (D. H. Conger, w, Madison)

Flood-inundation mapping:
Flood-inundation maps (H. D. Brice, w, W)

Flood-inundation mapping--Continued
Puerto Rico (w, San Juan):
Carolina-Río Grande area (W. J. Haire)
Fajardo-Luquillo area (W. J. Haire)
Lajas valley (W. J. Haire, K. G. Johnson)
Urban flood inundation, Río Piedras basin, (V. J. Latkovich)
Alabama, Jefferson County floodway evaluation (J. R. Harkins, w, Tuscaloosa)
Alaska, national program for managing flood losses (R. D. Lamke, w, Anchorage)
Arizona, flood-plain mapping (B. N. Aldridge, w, Tucson)
Georgia (M. Price, w, Atlanta)
Hawaii (C. J. Ewart, w, Honolulu)
Idaho (C. A. Thomas, Boise)
Illinois, northeastern (A. W. Noehre, w, Oak Park)
Kentucky (C. H. Hannum, w, Louisville)
Minnesota, flood-plain mapping (L. C. Guetzkow, w, St. Paul)
Missouri:
Hydrology of streams, St. Louis County (T. W. Alexander, w, St. Louis)
Metropolitan St. Louis Sewer District (D. W. Spencer, w, St. Louis)
New Jersey (S. L. Laskowski, J. G. Rooney, w, Trenton)
New York (B. Dunn, w, Albany)
South Dakota, 42 quadrangles (O. J. Larimer, w, Huron)
Tennessee, Nashville-Davidson County metropolitan area (L. G. Conn, w, Nashville)
Wisconsin, flood inundation study (C. L. Lawrence, w, Madison)

Flood investigations, areal:
Arkansas River basin, floods of June 1965—Colorado, Kansas, and New Mexico (R. J. Snipes, and others, w, Santa Fe, N. Mex.)
Flood reports (G. Edelen, H. D Brice, w, W)
Arizona:
Flood hydrology (B. N. Aldridge, w, Tucson)
Flood of September 1970, Arizona, Utah, Colorado (R. H. Roeske, w, Tucson)
Floods from small drainages in Flagstaff (B. N. Aldridge, w, Tucson)
Grand Canyon National Park (M. E. Cooley, w, Tucson)
Surface flow characteristics and infiltration from streamflow in upper San Pedro basin (B. N. Aldridge, w, Tucson)
Arkansas (M. S. Hines, w, Little Rock)
California, flood-plain mapping (A. O. Waananen, w, M)
Florida:
Flood investigations, Alafia basin (L. H. Motz, w, Tampa)
Flood investigations, Marion County (W. Anderson, w, Ocala)
Georgia, flood gaging (M. Price, w, Atlanta)
Hawaii, flood gaging (R. Nakahara, w, Honolulu)
Iowa:
Flood profiles, statewide (O. G. Lara, w, Iowa City)
Flood profiles and flood-plain information, Cedar Rapids (O. G. Lara, w, Iowa City)
Flood profiles and flood-plain information, Linn County (O. G. Lara, w, Iowa City)
Kansas, statewide (E. R. Hedman, w, Lawrence)
Mississippi, floods of 1966 and 1967 (K. V. Wilson, w, Jackson)

Flood investigations, areal--Continued
- New Jersey:
  - Flood warning (E. W. Moshinsky, w, Trenton)
  - Floods of August and September 1971 (S. J. Stankowski, w, Trenton)
- New York, peak discharge of ungaged streams (B. Dunn, w, Albany)
- Ohio, floods of July 4-8, 1969, in north-central Ohio (R. I. Mayo, w, Columbus)
- Tennessee, Nashville-Davidson County metropolitan area (L. G. Conn, w, Nashville)
- Virginia:
  - Fairfax County, flood hydrology (P. L. Soule, w, Fairfax)
  - Statewide (E. M. Miller, w, Richmond)
- Wyoming, flood-hydrograph investigations in selected drainage areas under 10 square miles (G. S. Craig, Jr., w, Cheyenne)

Fluorspar:
- Zoning, epithermal deposits (R. G. Worl, D)
- Colorado, Bonanza, and Poncha Springs quadrangles (R. E. Van Alstine, W)
- Illinois, southern (D. M. Pinckney, D)

Foreign nations, geologic investigations:
- Brazil, mineral resources and geologic training (M. G. White, Rio de Janeiro)
- Colombia, minerals exploration and appraisal (E. Irving, Bogotá)
- Liberia (W. L. Coonrad, Monrovia)
- Saudi Arabia, crystalline shield, geologic and minerals reconnaissance (T. H. Kiilsgaard, Jidda)

Foreign nations, hydrologic investigations. *See* Water resources, other countries.

Fuels, organic. *See* Coal; Oil shale; Petroleum and natural gas.

Gas, natural. *See* Petroleum and natural gas.

Geochemical distribution of the elements:
- Abundance of heavy metals in sedimentary rocks (H. A. Tourtelot, D)
- Botanical exploration and research (H. L. Cannon, D)
- Coding and retrieval of geologic data (T. G. Lovering, D)
- Data of geochemistry (M. Fleischer, W)
- Data of rock analyses (M. Hooker, W)
- Data systems (R. V. Mendes, D)
- Dispensions of elements in the zone of weathering (R. W. White, D)
- Light stable isotopes (J. R. O'Neil, M)
- Metals in volcaniclastic rocks (D. A. Lindsey, D)
- Sedimentary rocks, chemical composition (H. A. Tourtelot, D)
- Selenium, tellurium, and thallium, geochemical exploration (H. W. Lakin, D)
- California, Sierra Nevada batholith, geochemical study (F. Dodge, M)
- Colorado, Mt. Princeton igneous complex (P. Toulmin, W)
- Kentucky, geochemical census (J. J. Connor, D)
- Montana, Boulder batholith, petrochemistry (R. I. Tilling, W)

Geochemical prospecting methods:
- Application of silver-gold geochemistry to exploration (H. W. Lakin, D)
- Botanical exploration and research (H. L. Cannon, D)
- Elements in organic-rich material (F. N. Ward, D)
- Gamma-ray spectrometry (J. A. Pitkin, D)
- Geochemical exploration studies with volatile elements (J. H. McCarthy, D)

Geochemical prospecting methods--Continued
- Geochemical exploration techniques in alpine and subalpine environments (G. C. Curtin, D)
- Geochemical exploration techniques of the arid environment (M. A. Chaffee, D)
- Instrument development (W. W. Vaughn, D)
- Jasperoid—relations to ore deposits (T. G. Lovering, D)
- Mercury, geochemistry (A. P. Pierce, D)
- Mineral-exploration methods (G. B. Gott, D)
- Minor elements in detrital minerals (W. C. Overstreet, D)
- Mobile spectrographic laboratory (A. P. Marranzino, D)
- Ore-deposits controls (A. V. Heyl, Jr., D)
- Sulfides, accessory in igneous rocks (G. J. Neuerberg, D)
- Trace analyses (J. B. McHugh, D)
- Arizona:
  - Anomaly characterization (F. C. Canney, D)
  - Geochemical halos of mineral deposits (L. C. Huff, D)
- Colorado, Summitville alteration study (R. E. Van Loenen, D)
- Idaho, geochemical exploration in Coeur d'Alene (G. B. Gott, D)
- Maine, anomaly characterization (F. C. Canney, D)
- Nevada-Utah, geochemical halos (R. L. Erickson, D)
- New Mexico:
  - Basin and range part, geochemical reconnaissance (W. R. Griffitts, D)
  - Geochemical halos of mineral deposits (L. C. Huff, D)
- Puerto Rico (R. E. Learned, D)

Geochemistry, experimental:
- Environment of ore deposition (P. B. Barton, Jr., W)
- Experimental mineralogy (R. O. Fournier, M)
- Fluid inclusions in minerals (E. W. Roedder, W)
- Fluid zonation in metal deposits (J. T. Nash, M)
- Geologic thermometry (J. S. Huebner, W)
- Impact metamorphism (E. C. T. Chao, W)
- Kinetics of igneous processes (H. R. Shaw, W)
- Late-stage magmatic processes (G. T. Faust, W)
- Mineral equilibria, low-temperature (E-an Zen, W)
- Neutron activation (F. E. Senftle, W)
- Organic geochemistry (J. G. Palacas, D)
- Organometallic complexes, geochemistry (P. Zubovic, W)
- Solution-mineral equilibria (C. L. Christ, M)
- Stable isotopes and ore genesis (R. O. Rye, D)

Geochemistry, water:
- Atmospheric precipitation, chemistry (D. W. Fisher, w, W)
- Chemical constituents in ground water, spatial distribution (W. Back, w, W)
- Computer modeling of rock-water interactions (J. L. Haas, Jr., W)
- Corrosion and encrustation mechanisms in water supplies (F. E. Clarke, w, W)
- Elements, distribution in fluvial and brackish environments (V. C. Kennedy, w, M)
- Factors determining solute transfer in the unsaturated zone (J. Rubin, w, M)
- Geochemical controls of water quality (I. Barnes, w, M)
- Geochemical survey of waters of Missouri (G. L. Feder, w, Rolla, Mo.)
- Geochemistry of San Francisco Bay waters and sediments (D. H. Peterson, w, M)
- Hydrologic applications of quantitative mineralogy (R. Schoen, w, M)
- Hydrosolic metals and related constituents in natural water, chemistry (J. D. Hem, w, M)

Geochemistry, water--Continued
Hydrous metal oxides, their geochemistry and effect on water quality (E. A. Jenne, w, M)
Interaction of minerals and water in saline environments (B. F. Jones, w, W)
Mineralogic controls of the chemistry of ground water (B. B. Hanshaw, w, W)
Radiochemical surveillance (V. J. Janzer, w, D)
Solute balance, Abert and Summer Lakes, Oreg. (A. S. Van Denburgh, w, Carson City, Nev.)
Solute trends, Cold Spring playa lake, Nev. (A. S. Van Denburgh, w, Carson City, Nev.)
Trace elements in Missouri waters (G. L. Feder, w, Rolla, Mo.)
Alaska, technical assistance, Alaskan Air Command (H. L. Heyward, w, Anchorage)
Colorado, San Luis Valley, nitrate concentration of ground water (J. M. Klein, P. A. Emery, w, Pueblo)
See also Quality of water.
Geochemistry and petrology, field studies:
Alaskan ultramafics (A. L. Clark, M)
Basalt, genesis (T. L. Wright, W)
Basin and Range granites (D. E. Lee, D)
Epithermal deposits (R. G. Worl, D)
Geochemical halos, Utah-Nevada (R. L. Erickson, D)
Geochemical studies in Southeastern States (H. Bell III, Beltsville, Md.)
Geochemistry of diagenesis (K. J. Murata, M)
Geochemistry of sediments, San Francisco Bay, Calif. (D. S. McCulloch, M)
Hawaiian ankaramites (M. H. Beeson, M)
Humates, geology and geochemistry, Florida, New Mexico, and Wyoming (V. E. Swanson, D)
Inclusions in basaltic rocks (E. D. Jackson, M)
Layered intrusives (N. J Page, M)
Marine volcanic rocks (C. G. Engel, La Jolla, Calif.)
Mercury, geochemistry and occurrence (A. P. Pierce, D)
Meteorites, petrology (P. R. Brett, W)
Niobium and tantalum, distribution in igneous rocks (D. Gottfried, W)
Oceanic rocks and evolution of earth's crust (A. E. J. Engel, La Jolla, Calif.)
Oil shale, organic geochemistry (R. E. Miller, D)
Rare-earth elements, resources and geochemistry (J. W. Adams, D)
Regional metamorphic studies (H. L. James, M)
Residual minor elements in igneous rocks and veins (G. Phair, W)
Services (P. H. Held, M; H. J. Miller, W)
Solution transport of heavy metals (G. K. Czamanske, M)
Submarine volcanic rocks, properties (J. G. Moore, M)
Tertiary-Laramide intrusives of Colorado (E. J. Young, D)
Thermal waters, origin and characteristics (D. E. White, M)
Titanium, geochemistry and occurrence (N. Herz, Athens, Ga.)
Ultramafic rocks, petrology of alpine types (R. G. Coleman, M)
Arizona:
Ray program:
Mineral Mountain (T. G. Theodore, M)
Silicate mineralogy—geochemistry (N. G. Banks, M)
Supergene alteration (R. W. Luce, M)
Stocks (S. C. Creasey, M)
California:
Coast Range ultramafic rocks (R. S. Loney, M)
Geochemistry and petrology, field studies--Continued
California--Continued
Kings Canyon National Park (J. G. Moore, M)
Ritter Range metavolcanic rocks (R. S. Fiske, W)
Sierra Nevada metamorphism (B. A. Morgan III, W)
Colorado:
Petrology of the Mt. Princeton igneous complex (P. Toulmin, W)
Regional geochemistry—Denver urban area (H. A. Tourtelot, D)
Sandstones in the Spanish Peaks area, petrology and diagenesis (J. D. Vine, D)
San Juan volcanic field, east and central (P. W. Lipman, D)
Idaho, Wood River district (W. E. Hall, M)
Missouri:
Geochemical survey of rocks (J. J. Connor, D)
Geochemical survey of soils (R. R. Tidball, D)
Geochemical survey of vegetation (H. T. Shacklette, D)
Montana:
Bearpaw Mountains, petrology (B. C. Hearn, Jr., W)
Boulder batholith, petrochemistry (R. I. Tilling, W)
Wolf Creek area, petrology (R. G. Schmidt, W)
Nevada:
Igneous rocks and related ore deposits (M. L. Silberman, M)
Lewis district (T. J. Armbrustmacher, M)
Structural petrology of the northern Ruby Mountains (A. W. Snoke, M)
New Mexico:
Polvadera (volcanic) group, Jemez Mountains (R. A. Bailey, W)
Valles Mountains (R. L. Smith, W)
South Dakota:
Keystone pegmatite area (J. J. Norton, Rapid City)
Utah, Mule Ear (D. E. Stuart-Alexander, M)
Wyoming:
Absaroka volcanic rocks, eastern Yellowstone National Park (H. W. Smedes, D)
Rhyolitic rocks of Yellowstone National Park (R. L. Christiansen, D)
Geochronological investigations:
Carbon-14 method (M. Rubin, W)
Geochronology—Denver (C. E. Hedge, D)
Geochronology and rock magnetism (G. B. Dalrymple, M)
Igneous rocks and deformational periods (R. W. Kistler, M)
Lead-uranium, lead-thorium, and lead-alpha methods (T. W. Stern, W)
Post-Pleistocene alluviation and erosion in the lower San Juan drainage (D. O'Bryan, M. E. Cooley, T. C. Winter, w, W)
Radioactive-disequilibrium studies (J. N. Rosholt, D)
See also Isotope and nuclear studies.
Geologic mapping:
Geologic map of the United States (P. B. King, M)
Geologic mapping research (H. W. Smedes, D)
Map scale smaller than 1 inch to 1 mile:
Belt basin study (J. E. Harrison, D)
Colorado Plateau, geologic maps (2-degree sheets) (D. G. Wyant, D)
Columbia River basalt (D. A. Swanson, Hawaii National Park, Hawaii)
Sino-Soviet terrain atlas (J. Rachlin, W)
Alaska:
Brooks Range, southern part (W. P. Brosgé, M)

Geologic mapping--Continued

Map scale smaller than 1 inch to 1 mile--Continued

Alaska--Continued

Charley River quadrangle (E. E. Brabb, M)
Compilations of Alaska geology (E. H. Lathram, M)
Delong Mountains quadrangle (I. L. Tailleur, M)
Geologic map (H. M. Beikman, M)
Hughes-Shungnak area (W. W. Patton, Jr., M)
Iliamna quadrangle (R. L. Detterman, M)
Northern part, petroleum investigations (G. Gryc, M)
Point Hope quadrangle (I. L. Tailleur, M)
St. Lawrence Island (W. W. Patton, Jr., M)
Seward Peninsula (C. L. Sainsbury, D)
Southeast Alaska (D. A. Brew, M)

Arizona, San Pedro-Gila area (S. C. Creasey, M)
Arkansas (B. R. Haley, Little Rock)
Colorado:
Oil-shale investigations (D. C. Duncan, W)
Denver 2-degree quadrangle (B. Bryant, D)
Geologic map (O. L. Tweto, D)
Limon 2-degree quadrangle (J. A. Sharps, D)
Montrose 2-degree quadrangle (W. J. Hail, Jr., D)
Pueblo 2-degree quadrangle (G. R. Scott, D)
Idaho:
Challis Volcanics (D. H. McIntyre, D)
Preston 2-degree quadrangle (S. S. Oriel, D)
Snake River plain, central part, volcanic petrology (H. E. Malde, D)
Spokane-Wallace region (A. B. Griggs, M)
Montana, Spokane-Wallace region (A. B. Griggs, M)
Nevada:
Elko County (R. A. Hope, M)
Elko County, western (R. R. Coats, M)
Geologic map (J. H. Stewart, M)
Lander County (J. H. Stewart, M)
Lincoln County, Tertiary rocks (E. B. Ekren, D)
Nye County, northern part (F. J. Kleinhampl, M)
Nevada Test Site, special studies (L. M. Gard, E. B. Ekren, D)
North Carolina:
Greensboro 2-degree quadrangle (L. Glover, III, Blacksburg, Va.)
Knoxville 2-degree quadrangle (J. B. Hadley, Beltsville, Md.)
Winston-Salem 2-degree quadrangle (D. W. Rankin, G. H. Espenshade, W)
Oregon (G. W. Walker, M)
South Carolina, Knoxville 2-degree quadrangle (J. B. Hadley, W)
Tennessee:
Knoxville 2-degree quadrangle (J. B. Hadley, W)
Winston-Salem 2-degree quadrangle (D. W. Rankin, G. H. Espenshade, W)
Utah, Glen Canyon Recreation Area (A. L. Brokaw, D)
Virginia, Winston-Salem 2-degree quadrangle (D. W. Rankin, G. H. Espenshade, W)
Washington, Spokane-Wallace region (A. B. Griggs, M)
Wyoming:
Geologic map (J. D. Love, D)
Preston 2-degree quadrangle (S. S. Oriel, D)

Map scale 1 inch to 1 mile, and larger:

Antarctica, Pensacola Mountains (D. L. Schmidt, D)
District of Columbia, Washington metropolitan area (H. W. Coulter, C. F. Withington, W)

Geologic mapping--Continued

Map scale 1 inch to 1 mile, and larger--Continued

Puerto Rico (R. P. Briggs, San Juan)
Alaska:
Annette Island (H. C. Berg, M)
Bering River coal field (A. A. Wanek, c, Anchorage)
Cape Beaufort-Corwin Bluffs coal field (A. A. Wanek, c, Anchorage)
Fairbanks district (R. M. Chapman, M)
Kukpowruk River coal field (A. A. Wanek, c, Anchorage)
Livengood quadrangle (R. M. Chapman, M)
Nelchina area Mesozoic investigations (A. Grantz, M)
Nenana coal investigations (C. Wahrhaftig, M)
Nome area (C. L. Hummel, M)
Arizona:
Bradshaw Mountains (C. A. Anderson, M)
Cochise County, southern part (P. T. Hayes, D)
Cummings Mesa quadrangle (F. Peterson, c, D)
Garnet Mountain quadrangle (P. M. Blacet, M)
Gunsight Butte SW quadrangle (F. Peterson, c, D)
Mt. Wrightson quadrangle (H. Drewes, D)
Ray district, porphyry copper (H. R. Cornwall, M)
California:
Big Maria Mountains (W. B. Hamilton, D)
Bucks Lake quadrangle (A. Hietanen-Makela, M)
Coast Range, ultramafic rocks (E. H. Bailey, M)
Condrey Mountain-Hornbrook quadrangle (P. E. Hotz, M)
Furnace Creek area (J. F. McAllister, M)
Klamath Mountains, southern part (W. P. Irwin, M)
Malibu Beach quadrangle (R. F. Yerkes, M)
Merced Peak quadrangle (D. L. Peck, W)
Point Dume and Triunto quadrangles (R. H. Campbell, M)
Sacramento Valley, northwest part (R. D. Brown, Jr., M)
Searles Lake area (G. I. Smith, M)
Sierra Nevada batholith (P. C. Bateman, M)
Colorado:
Aspen 15-minute quadrangle (B. Bryant, D)
Bonanza quadrangle (R. E. Van Alstine, W)
Buckhorn Lakes quadrangle (R. G. Dickinson, c, D)
Central City area (R. B. Taylor, D)
Citadel Plateau (G. A. Izett, c, D)
Cochetopa area (J. C. Olson, D)
Courthouse Mountain quadrangle (R. G. Dickinson, c, D)
Denver basin, Tertiary coal zone (P. E. Soister, c, D)
Denver metropolitan area (R. M. Lindvall, D)
Disappointment Valley, geology and coal resource (D. E. Ward, D)
Front Range, northeastern part, Fort Collins area (W. A. Braddock, D)
Indian Hills Precambrian (B. H. Bryant, D)
Jefferson quadrangle (F. Barker, D)
Kremmling quadrangle (G. A. Izett, c, D)
Middle Park—North Park area (G. A. Izett, c, D)
Montezuma quadrangle (F. Barker, D)
Niwot quadrangle (D. E. Trimble, D)
Northern Park Range (G. L. Snyder, D)
Platoro caldera and related volcanic rocks, southeastern San Juan Mountains (P. W. Lipman, D)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Colorado--Continued
Poncha Springs quadrangle (R. E. Van Alstine, W)
Rangely NE quadrangle (H. L. Cullins, c, Metairie, La)
San Juan mining area (R. G. Luedke, W)
Savery quadrangle (C. S. V. Barclay, c, D)
Squaw Pass and Evergreen quadrangles (D. M. Sheridan, D)
Straight Creek tunnel (F. T. Lee, D)
Strasburg NW and SW quadrangles (P. E. Soister, c, D)
Ward and Gold Hill quadrangles (D. J. Gable, D)
Washboard Rock quadrangle (R. G. Dickinson, c, D)
Watkins and Watkins SE quadrangles (P. E. Soister, c, D)
Wet Mountains (Q. D. Singewald, Beltsville, Md.)
Connecticut:
Cooperative mapping program (L. R. Page, Boston, Mass.)
Taconic sequence (E-an Zen, W)
Florida, Attapulgus-Thomasville area, fuller's earth deposits (S. H. Patterson, Beltsville, Md.)
Georgia, Attapulgus-Thomasville area, fuller's earth deposits (S. H. Patterson, Beltsville, Md.)
Idaho:
Alpine quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Bayhorse area (S. W. Hobbs, D)
Goat Mountain quadrangle (M. H. Staatz, D)
Grouse quadrangle (B. A. Skipp, D)
Hawley Mountain quadrangle (W. J. Mapel, D)
Henrys Lake area (I. J. Witkind, D)
Malad southeast quadrangle (S. S. Oriel, D)
Montour quadrangle (H. E. Malde, D)
Mt. Spokane quadrangle (A. E. Weissenborn, Spokane, Wash.)
Palisades Dam quadrangle (D. A. Jobin, c, D)
Patterson quadrangle (E. T. Ruppel, D)
Poker Peak quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Wood River district (W. E. Hall, M)
Yandell Springs quadrangle (D. E. Trimble, D)
Yellow Pine quadrangle (B. F. Leonard, D)
Indiana:
Ohio River Quaternary (M. P. Weiss, DeKalb, Ill.)
Ohio River valley, Quaternary geology (L. L. Ray, W)
Kentucky:
Appalachian folded belt, southern part (L. D. Harris, Knoxville, Tenn.)
Cooperative mapping program (P. W. Richards, Lexington)
Maine:
Blue Hill quadrangle (D. B. Stewart, W)
Castine quadrangle (D. B. Stewart, W)
Chain Lakes area (E. L. Boudette, Hanover, N.H.)
Orland quadrangle (D. R. Wones, W)
Rumford quadrangle (R. H. Moench, D)
Southern Aroostook County (L. Pavlides, W)
The Forks quadrangle (F. C. Canney, D)
Maryland:
Cecil County (L. C. Conant, W)
Delmarva Peninsula (J. P. Owens, Beltsville)
New Windsor quadrangle (G. W. Fisher, Beltsville)
Washington, D.C., metropolitan area (H. W. Coulter, C. F. Withington, W)
Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Massachusetts:
Cooperative mapping program (L. R. Page, Boston)
Taconic sequence (E-an Zen, W)
Michigan:
Gogebic Range, eastern (V. A. Trent, W)
Gogebic Range, western part (R. G. Schmidt, W)
Greenland and Rockland quadrangles (J. W. Whitlow, Beltsville, Md.)
Isle Royale National Park (N. K. Huber, M)
Western Negaunee quadrangle (G. C. Simmons, D)
Montana:
Alberton quadrangle (J. D. Wells, D)
Bearpaw Mountains, petrology (B. C. Hearn, Jr., W)
Butte North quadrangle (H. W. Smedes, D)
Cooke City quadrangle (J. E. Elliott, D)
Craig quadrangle (R. G. Schmidt, W)
Crazy Mountains Basin (B. A. Skipp, D)
Decker quadrangle (B. E. Law, c, Casper, Wyo.)
Diamond City No. 3 quadrangle (W. B. Myers, D)
Hardy quadrangle (K. S. Soward, c, Casper, Wyo.)
Henrys Lake area (I. J. Witkind, D)
Holter Lake quadrangle (G. D. Robinson, D)
Jordan quadrangle (G. D. Mowat, c, Billings)
Lemhi Pass quadrangle (M. H. Staatz, D)
Little Prickly Pear 15-minute quadrangle (G. D. Robinson, D)
Melrose phosphate field (G. D. Fraser, c, D)
Monarch quadrangle, B. E. Barnum, c, D)
Northern Pioneer Range, geologic environment E-an Zen, W)
Pearl School quadrangle, (F. N. Murray, c, Casper, Wyo.)
Ranchester quadrangle, (B. E. Barnum, c, D)
Rocky Reef quadrangle (K. S. Soward, c, Casper, Wyo.)
Sun River area (M. R. Mudge, W)
Wolf Creek area, petrology (R. G. Schmidt, W)
Nevada:
Austin quadrangle (E. H. McKee, M)
Bellevue Peak quadrangle (T. B. Nolan, W)
Carlin region (J. F. Smith, Jr., D)
Dun Glen quadrangle (D. H. Whitebread, M)
Jordan Meadow and Disaster Peak quadrangles (R. C. Greene, M)
Kobeh Valley (T. B. Nolan, W; C. W. Merriam, M)
Lewis district (T. J. Armbrustmacher, M)
Lida Wash quadrangle (K. B. Krauskopf, M)
Midas-Jarbidge area (R. R. Coats, M)
Nevada Test Site:
Geologic studies (E. B. Ekren, D)
Site studies (P. P. Orkild, D)
Pinto Summit quadrangle (T. B. Nolan, W)
Spruce Mountain 4 quadrangle (G. D. Fraser, c, D)
New Hampshire, Milford 15-minute quadrangle, surficial (C. Koteff, Boston, Mass.)
New Jersey, Delaware River basin, lower part (J. P. Owens, Beltsville, Md.)
New Mexico:
Acoma area (C. H. Maxwell, D)
Church Rock-Smith Lake (C. T. Pierson, D)
Cretaceous stratigraphy, San Juan basin (E. R. Landis, D)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
New Mexico--Continued
Gallup West quadrangle (J. E. Fassett, c, Farmington)
Hillsboro quadrangle (D. C. Hedlund, D)
Madrid quadrangle (G. O. Bachman, D)
Manuelito quadrangle (J. E. Fassett, c, Farmington)
Manzano Mountains (D. A. Myers, D)
Raton coal basin, western part (C. L. Pillmore, D)
Rowe and Bull Canyon quadrangles (R. B. Johnson, D)
Samson Lake quadrangle (J. E. Fassett, c, Farmington)
Thoreau area (J. F. Robertson, D)
Twin Butte quadrangle (J. E. Fassett, c, Farmington)
Twin Sisters quadrangle (T. L. Finnell, D)
Valles Mountains, petrology (R. L. Smith, W)
Wingate area (M. W. Green, D)
New York:
Pope Mills and Richville quadrangles (C. E. Brown, W)
Taconic sequence (E-an Zen, W)
North Carolina:
Central Piedmont (A. A. Stromquist, D)
Northern slate belt, North Carolina-Virginia (V. M. Seiders, Beltsville, Md.)
North Dakota:
Clark Butte 15-minute quadrangle (G. D. Mowat, c, Billings, Mont.)
Dengate quadrangle (C. S. V. Barclay, c, D)
Glen Ullin quadrangle (C. S. V. Barclay, c, D)
Heart Butte and Heart Butte NW quadrangles (E. V. Stephens, c, M)
New Salem quadrangle (H. L. Smith, c, D)
North Almont quadrangle (H. L. Smith, c, D)
White Butte 15-minute quadrangle (K. S. Soward, c, Casper, Wyo.)
Oregon, Burnt River Canyon (R. P. Ashley, M)
Pennsylvania:
Allentown 15-minute quadrangle (A. A. Drake, Jr., W)
Anthracite region, flood control (M. J. Bergin, W)
Claysville-Avella area (S. P. Schweinfurth, W)
Delaware River basin, lower part (J. P. Owens, Beltsville, Md.)
Hyndman area (W. de Witt, Jr., Beltsville, Md.)
Mather-Garards Fort area (B. H. Kent, D)
Middle Delaware basin (A. A. Drake, Jr., W)
Southern anthracite field (G. H. Wood, Jr., W)
Waynesburg-Oak Forest area (J. B. Roen, Beltsville, Md.)
Western Middle anthracite field (H. Arndt, W)
Wind Gap and adjacent quadrangles (J. B. Epstein, Beltsville, Md.)
South Dakota:
Black Hills Precambrian (J. A. Redden, Hill City)
Northern Black Hills (R. W. Bayley, M)
Rapid City area (J. M. Cattermole, D)
Tennessee:
Appalachian folded belt, southern part (L. D. Harris, Knoxville)
Midway belt, western part of State (W. S. Parks, w, Nashville)
Texas:
Coastal plain, geophysical and geological studies (D. H. Eargle, Austin)
Tilden-Loma Alta area (K. A. Dickinson, D)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Utah:
Basin Canyon quadrangle (F. Peterson, c, D)
Big Hollow Wash quadrangle (F. Peterson, c, D)
Bingham Canyon district (E. W. Tooker, M)
Blackburn Canyon quadrangle (F. Peterson, c, D)
Butler Valley quadrangle (W. E. Bowers, c, D)
Canaan Creek quadrangle (H. D. Zeller, c, D)
Canaan Peak quadrangle (W. E. Bowers, c, D)
Carcass Canyon quadrangle (H. D. Zeller, c, D)
Coal-mine bumps (F. W. Osterwald, D)
Collet Top quadrangle (H. D. Zeller, c, D)
Confusion Range (R. K. Hose, M)
Crawford Mountains (W. C. Gere, c, M)
Cummings Mesa NE and SE quadrangles (F. Peterson, c, D)
Dave Canyon quadrangle (H. D. Zeller, c, D)
Death Ridge quadrangle (H. D. Zeller, c, D)
East-of-the-Navajo quadrangle (F. Peterson, c, D)
Fourmile Bench quadrangle (W. E. Bowers, c, D)
Griffin Point quadrangle (W. E. Bowers, c, D)
Gunsight Butte SW ¼ quadrangle (F. Peterson, c, D)
Henrieville quadrangle (W. E. Bowers, c, D)
Horse Mountain quadrangle (W. E. Bowers, c, D)
Iron Springs district (P. D. Rowley, D)
Jessen Butte quadrangle (E. M. Schell, c, Casper, Wyo.)
Needle Eye Point quadrangle (H. D. Zeller, c, D)
Oak City area (D. J. Varnes, D)
Ogden 4 NW quadrangle (R. J. Hite, c, D)
Park City district (C. S. Bromfield, D)
Pete's Cove quadrangle (H. D. Zeller, c, D)
Pine Lake quadrangle (W. E. Bowers, c, D)
Raft River Mountains (R. R. Compton, Stanford, Calif.)
Salt Lake City and vicinity (R. Van Horn, D)
San Francisco district (D. M. Lemmon, M)
Seep Flat quadrangle (E. V. Stephens, c, M)
Sheeprock Mountains, West Tintic district (H. T. Morris, M)
Ship Mountain Point quadrangle (H. D. Zeller, c, D)
Sooner Bench quadrangle (F. Peterson, c, D)
Sunset Flat quadrangle (F. Peterson, c, D)
Upper Valley quadrangle (W. E. Bowers, c, D)
Vernal phosphate area (E. M. Schell, c, Casper, Wyo.)
Wah Wah Summit quadrangle (L. F. Hintze, Salt Lake City)
Wide Hollow Reservoir (E. V. Stephens, c, M)
Willard Peak area (M. D. Crittenden, Jr., M)
Virginia:
Appalachian folded belt, southern part (L. D. Harris, Knoxville, Tenn.)
Big A Mountain quadrangle (R. L. Miller, W)
Delmarva Peninsula (J. P. Owens, Beltsville, Md.)
Northeast area (L. Pavlides, Beltsville, Md.)
Northern slate belt, North Carolina-Virginia (Lynn Glover, Beltsville, Md.)
Quantico 15-minute quadrangle (R. B. Mixon, Beltsville, Md.)
Washington, D.C., metropolitan area (H. W. Coulter, W)
Washington:
Chewelah No. 4 quadrangle (F. K. Miller, M)
Glacier Park area (F. W. Cater, D)

Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Washington--Continued
Loomis quadrangle (C. D. Rinehart, M)
Mt. St. Helens and Spirit Lake quadrangles, (C. A. Hopson, Santa Barbara, Calif.)
Mt. Spokane quadrangle (A. E. Weissenborn, Spokane)
Newport 30-minute quadrangle (F. K. Miller, M)
Olympic Peninsula, eastern part (W. M. Cady, D)
Puget Sound Basin (D. R. Mullineaux, D)
Stevens County (R. G. Yates, M)
Twin Lakes quadrangle (G. E. Becraft, W)
Wisconsin:
Black River Falls and Hatfield quadrangles (H. Klemic, W)
Lead-zinc district (W. S. West, Platteville)
Wyoming:
Albany and Keystone quadrangles (M. E. McCallum, Fort Collins, Colo.)
Alkali Butte quadrangle (M. W. Reynolds, D)
Alpine quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Badwater Creek (R. E. Thaden, D)
Bailey Lake quadrangle (M. L. Schroeder, c, D)
Browns Hill quadrangle (C. S. V. Barclay, c, D)
Bull Creek quadrangle (M. L. Schroeder, c, D)
Cache Creek quadrangle (D. A. Jobin, c, D)
Camp Davis quadrangle (D. A. Jobin, c, D)
Clause Peak quadrangle (M. L. Schroeder, c, D)
Cokeville and adjacent quadrangles (W. W. Rubey, Los Angeles, Calif.)
Cottonwood Rim quadrangle (C. S. V. Barclay, c, D)
Crawford Mountains (W. C. Gere, c, M)
Creston Junction quadrangle (R. B. Sanders, c, D)
Deer Creek quadrangle (D. A. Jobin, c, D)
Devils Tooth quadrangle (W. G. Pierce, M)
Ferry Peak quadrangle (D. A. Jobin, c, D)
Gas Hills uranium district (F. C. Armstrong, Spokane, Wash.)
Gillette Coal Field (W. L. Rohrer, c, Casper)
Grand Teton National Park (J. D. Love, Laramie)
Grieve Reservoir quadrangle (C. S. V. Barclay, c, D)
Hoback Peak quadrangle (D. A. Jobin, c, D)
Hulett Creek (C. H. Maxwell, D)
Jackson 7½-minute quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Ketchum Buttes quadrangle (C. S. V. Barclay, c, D)
Lander area phosphate reserve (W. L. Rohrer, c, Casper)
Monarch quadrangle, (B. E. Barnum, c, D)
Observation Peak quadrangle (H. F. Albee, c, Salt Lake City, Utah)
Oil Mountain quadrangle (W. H. Laraway, c, Casper)
Pickle Pass quadrangle (D. A. Jobin, c, D)
Pilot Peak quadrangle (W. G. Pierce, M)
Pine Creek quadrangle (D. A. Jobin, c, D)
Poison Spider quadrangle (W. H. Laraway, c, Casper)
Ranchester quadrangle (B. E. Barnum, c, D)
Reid Canyon quadrangle (W. H. Laraway, c, Casper)
Riner quadrangle (R. B. Sanders, c, D)
Sagebrush Park quadrangle (L. J. Schmitt, Jr., D)
Savery quadrangle (C. S. V. Barclay, c, D)
Sheridan Pass quadrangle (W. L. Rohrer, c, Casper)
Geologic mapping--Continued
Map scale 1 inch to 1 mile, and larger--Continued
Wyoming--Continued
Ship Mountain Point quadrangle (H. D. Zeller, c, D)
Square Top Butte quadrangle (W. H. Laraway, c, Casper)
Stewart Peak quadrangle (D. A. Jobin, c, D)
Sweetwater County, Green River Formation (W. C. Culbertson, D)
Taylor Mountain quadrangle (M. L. Schroeder, c, D)
Tullis quadrangle, (C. S. V. Barclay, c, D)
Wapiti quadrangle (W. G. Pierce, M)
Wind River Basin, regional stratigraphy (W. R. Keefer, D)
Geomorphology:
Landforms of the present, Great Plains (D. E. Trimble, D)
Mudflow studies (D. R. Crandell, D)
Ohio River Quaternary (M. P. Weiss, DeKalb, Ill.)
Ohio River Valley, geologic development (L. L. Ray, W)
Indiana, Ohio River Quaternary (M. P. Weiss, Dekalb, Ill.)
Wyoming:
Wind River Mountains, Quaternary geology (G. M. Richmond, D)
Yellowstone National Park, glacial and postglacial geology (G. M. Richmond, D)
See also Sedimentation; Geochronology.
Geophysics, regional:
Aeroradioactivity surveys, California, San Andreas fault (W. H. Jackson, M)
Borehole geophysics (C. J. Zablocki, D)
Crust and upper mantle:
Aeromagnetic interpretation of metamorphic rocks (I. Zietz, W)
Aeromagnetic studies of the United States (I. Zietz, W)
Analysis of traveltime data (J. C. Roller, M)
Fault-zone geophysical studies (W. H. Jackson, M)
Seismologic studies (J. P. Eaton, M)
Groundwater geophysics (W. D. Stanley, D)
National aeromagnetic survey (D. R. Mabey, D)
Program and systems development (G. I. Evenden, W. L. Anderson, D)
Remote sensing:
Airborne methods, research (F. C. Frischknecht, D)
Environmental effects (K. Watson, D)
Geochemical anomalies (F. C. Canney, D)
Geologic applications (G. W. Greene, M)
Infrared laboratory (G. W. Greene, M)
Infrared spectrometry and imagery (R. M. Moxham, W)
Infrared studies of volcanoes (J. D. Friedman, W)
New Mexico, Rio Grande graben and Valles caldera (L. E. Cordell, D)
Radar interpretation (A. N. Kover, W)
Remote sensors—automatic data processing (K. Watson, D)
Rock magnetics, northern Rocky Mountains (W. F. Hanna, M)
See also Remote sensing, hydrologic applications.
Remote sensing and advanced techniques, geologic applications (G. D. Robinson, D)
Seismotectonic provinces map (J. B. Hadley, Beltsville, Md.)
Ultramafic rocks, geophysical studies, intrusions (G. A. Thompson, M)
Upper mantle gravity studies, west of the Mississippi (D. R. Mabey, D)

Geophysics, regional--Continued
- Antarctica, Pensacola Mountains, geophysical studies (J. C. Behrendt, Monrovia, Liberia)
- Basin and Range, geophysical studies (W. E. Davis, M)
- Florida Continental Shelf, gravity studies (H. Krivoy, Corpus Christi, Tex.)
- New England:
  - Geophysical studies (M. F. Kane, W)
  - Magnetic properties of rocks (A. Griscom, M)
- Pacific States, geophysical studies (A. Griscom, M)
- Rocky Mountains, northern (D. L. Peterson, D, M. D. Kleinkopf, W)
- Southeastern States geophysical studies (P. Popenoe, W)
- United States, aeromagnetic surveys (E. R. King, W)
- Yellowstone National Park, geophysical study (H. R. Blank, Eugene, Oreg.)
- Alaska, regional gravity surveys (D. F. Barnes, M)
- Arizona, Safford Valley, geophysical studies (G. P. Eaton, D)
- California:
  - Los Angeles basin, gravity study (T. H. McCulloh, M)
  - San Andreas fault, ground studies (W. F. Hanna, M)
  - Sierra Nevada, geophysical studies (H. W. Oliver, M)
- Colorado:
  - Bouguer anomaly gravity map (J. C. Behrendt, D)
  - Middle Park-North Park basins, geophysical studies (J. C. Behrendt, Monrovia, Liberia)
  - San Juan Mountains, geophysical studies (D. Plouff, M)
- District of Columbia, eastern Piedmont, geophysical studies (S. K. Neuschel, W)
- Idaho, Snake River Plain (D. L. Peterson, D)
- Maine, Island Falls quadrangle, electromagnetic mapping (F. C. Frischknecht, W)
- Maryland:
  - Cooperative survey (J. L. Meuschke, D)
  - Piedmont (J. W. Allingham, W)
- Massachusetts:
  - Application of geology and seismology to public-works planning (L. R. Page, Boston)
  - Cooperative survey (J. L. Meuschke, D)
  - Geophysical studies (M. F. Kane, W)
- Minnesota:
  - Keweenawan rocks, magnetic studies (K. G. Books, W)
  - Southern part, aeromagnetic survey (E. R. King, W)
- Nevada:
  - Applied geophysics, Nevada Test Site (G. D. Bath, D)
  - Engineering geophysics, Nevada Test Site (R. D. Carroll, D)
- New Hampshire, aeromagnetic survey (R. W. Bromery, Amherst, Mass.)
- North Carolina, Piedmont (J. W. Allingham, W)
- Pennsylvania, magnetic properties of rocks (A. Griscom, M)
- Texas, coastal plain, geophysical and geological studies (D. H. Eargle, Austin)
- Virginia, eastern Piedmont, geophysical studies (S. K. Neuschel, W)

Geophysics, theoretical and experimental:
- Crustal studies (ARPA) (I. Zietz, W)
- Earth structure studies (J. H. Healy, M)
- Earthquakes, local seismic studies (J. P. Eaton, M)
- Elastic and inelastic properties of earth materials (L. Peselnick, M)
- Electrical properties of rocks (R. D. Carroll, D)
- Experimental rock mechanics (C. B. Raleigh, M)

Geophysics, theoretical and experimental--Continued
- Geophysical data, interpretation using electronic computers (R. G. Henderson, W)
- Geophysical program and systems development (G. E. Andreasen, W)
- Ground motion studies (J. H. Healy, M)
- Induced polarization (L. A. Anderson, D. B. Hoover, D)
- Infrared and ultraviolet radiation studies (R. M. Moxham, W)
- In-situ stress (R. V. de la Cruz, M)
- Magnetic and luminescent properties (F. E. Senftle, W)
- Magnetic model studies (G. E. Andreason, W)
- Magnetic properties laboratory (M. E. Beck, Jr., Bellingham, Wash.)
- Remanent magnetization of rocks (R. R. Doell, M)
- Resistivity interpretation (A. A. R. Zohdy, D)
- Rock behavior at high temperature and pressure (E. C. Robertson, W)
- Stress studies (C. B. Raleigh, M)
- Thermodynamic properties of rocks (R. A. Robie, W)
- Ultramafic intrusions, geophysical studies (G. A. Thompson, M)
- Volcano geophysics (E. T. Endo, M)
- California, mass properties of oil field rocks (L. A. Beyer, M)

Geothermal investigations:
- Borehole logging (C. J. Zablocki, D)
- Electrical and electromagnetic methods (D. R. Mabey, D)
- Geochemical indicators (A. H. Truesdell, M)
- Geothermal studies (A. H. Lachenbruch, M)
- Remote sensing (K. Watson, D)
- Rock-water interactions (R. O. Fournier, M)
- California:
  - Geology of Long Valley - Mono Basin (R. A. Bailey, W)
  - Geology of the Geysers-Clear Lake area (B. C. Hearn, Jr., W)
  - Seismic noise, the Geysers area (H. M. Iyer, M)
- Nevada, geothermal reconnaissance (R. K. Hose, M)
- Wyoming, Yellowstone thermal areas, geology (L. J. P. Muffler, M)

Glacial geology, Antarctica, Pensacola Mountains (D. L. Schmidt, D)

Glaciology:
- Glaciological research, International Hydrological Decade (M. F. Meier, w, Tacoma, Wash.)
- Ice dynamics (W. J. Campbell, w, Tacoma, Wash.)
- Water, ice, and energy balance of mountain glaciers, and ice physics (M. F. Meier, w, Tacoma, Wash.)
- Alaska (L. R. Mayo, w, Fairbanks)
- Montana, Glacier National Park, Grinnell and Sperry Glaciers (A. Johnson, w, Grand Forks, N. Dak.)

Gold:
- Composition related to exploration (J. C. Antweiler, D)
- Microprobe analyses (G. A. Desborough, D)
- Placer deposits, New Mexico (K. Segerstrom, D)
- Alaska:
  - Gulf of Alaska, nearshore (E. H. Lathram, M)
  - Seward Peninsula, nearshore (D. M. Hopkins, M)
- Arizona, Gold Basin-Lost Basin district (P. M. Blacet, M)
- California:
  - Klamath Mountains (P. E. Hotz, M)
- Great Lakes region (D. A. Seeland, D)
- Idaho and Utah, conglomerates (T. E. Mullens, D)

Gold--Continued
Montana:
Confederate Gulch (W. B. Myers, D)
Cooke City quadrangle (J. E. Elliott, D)
Southwestern part, ore deposits (K. L. Wier, D)
Nevada:
Aurora and Bodie districts, Nevada-California (F. J. Kleinhampl, M)
Carlin mine (A. S. Radtke, M)
Comstock district (D. H. Whitebread, M)
Cortez window and vicinity (J. D. Wells, D)
Dun Glen quadrangle (D. H. Whitebread, M)
Goldfield district (R. P. Ashley, M)
Shoshone Range (C. T. Wrucke, M)
North Carolina, Gold Hill area (A. A. Stromquist, D)
Oregon-Washington, nearshore area (P. D. Snavely, Jr., M)
South Dakota:
Keystone area (W. H. Raymond, D)
Northern Black Hills (R. W. Bayley, M)
Wyoming:
Atlantic City district (W. C. Prinz, W)
Northwestern part, conglomerates (J. C. Antweiler, D)
See also Heavy metals.
Ground-water—surface-water relations:
Flow losses in ephemeral stream channels (R. F. Hadley, w, D)
Kansas (W. M. Kastner, w, Lawrence)
Kentucky, ground water in alluvium of Ohio River Valley, development and management (H. F. Grubb, w, Louisville)
New Mexico:
Pecos River—miscellaneous (G. E. Welder, w, Roswell)
North Carolina, effect of channel improvement on hydrologic conditions in Creeping Swamp (M. D. Winner, W. G. Stamper, w, Raleigh)
Wisconsin:
Effects of fish hatchery water management on the hydrologic system (R. P. Novitzki, w, Madison)
Hydrologic effects of dredging small spring ponds (W. J. Rose, w, Madison)
Hydrologic system of the Lake Wingra basin and the effects of urban development on the system (J. H. Green, w, Madison)
Hydrology of proposed recreation reservoirs (W. A. Gebert, w, Madison)
Heavy metals:
Abundance in sedimentary rocks (H. A. Tourtelot, D)
Hydro- and bio-geochemistry (T. T. Chao, D)
Mineral paragenesis (J. T. Nash, M)
Mineralogy (F. A. Hildebrand, D)
Regional variation in heavy-metals content of Colorado Plateau stratified rocks (R. A. Cadigan, D)
Solution transport (G. K. Czamanske, M)
Appalachian region:
Mineral resources, Connecticut-Massachusetts (J. P. D'Agostino, Beltsville, Md.)
South-central (A. A. Stromquist, D)
Southeastern, sediments (J. P. Minard, W)
Rocky Mountain region, fossil beach placers (R. S. Houston, Laramie, Wyo.)
Southeastern states, geochemical studies (H. Bell III, Beltsville, Md.)
Alaska:
Gulf of Alaska, nearshore placers (Erk Reimnitz, M)
Heavy metals--Continued
Alaska--Continued
Hogatza trend (T. P. Miller, M)
Seward Peninsula (C. L. Sainsbury, D)
Southeastern part (D. A. Brew, M)
Southern Alaska Range (B. L. Reed, M)
Southwestern part (J. M. Hoare, M)
Yukon-Tanana Upland (H. L. Foster, M)
Colorado, San Juan Mountains, northwestern (R. P. Fischer, D)
Idaho, conglomerates (T. E. Mullens, D)
Maine, West Pembroke (R. H. Moench, D)
Nevada:
Aurora and Bodie districts, Nevada-California (F. J. Kleinhampl, M)
Basin and Range (D. R. Shawe, D)
Copper Canyon deposit (T. G. Theodore, M)
North Carolina, southwestern part, reconnaissance (J. W. Whitlow, Beltsville, Md.)
Utah:
Conglomerates (T. E. Mullens, D)
Geologic controls (A. V. Heyl, D)
Hydraulics, ground water:
Applicability of the unsaturated flow theory to the phenomena of infiltration and drainage (J. Rubin, w, M)
Computer analysis—ground-water problems (S. S. Papadopulos, w, W)
Effects of initial time step on model studies (R. T. Hurr, w, D)
Mechanics of aquifer systems (J. F. Poland, w, Sacramento, Calif.)
Mechanics of ground-water flow (G. F. Pinder w, W)
Permeability distribution study—Atlantic Coastal Plain (P. M. Brown, w, Raleigh, N.C.)
Regional hydrologic system analysis—hydrodynamics (R. R. Bennett, w, W)
Regional hydrologic system analysis—permeability distribution (J. D. Bredehoeft, w, W)
Response of well-aquifer systems to explosions D. D. Gonzalez, w, D)
Theory of multiphase flow—applications (E. P. Weeks, w, D)
Transient phenomena in ground-water flow (C. E. Mongan, w, Boston, Mass.)
Transport processes in fluid flows (A. Ogata, w, Honolulu, Hawaii)
Velocities of ground water and radionuclides at the Amargosa tracer site, Nevada E. H. Cordes, w, D)
Colorado, digital models to test water management plans (O. J. Taylor, R. R. Luckey, w, D)
Kansas, gravity flow of water in soils and aquifers, western part of State (R. C. Prill, w, Garden City)
New Mexico, effects of detonations (F. C. Koopman, w, Albuquerque)
New York, influx to Lake Ontario (E. C. Rhodehamel, w, Albany)
Hydraulics, surface flow:
Channel characteristics, California:
Channel capacity, San Joaquin River (K. W. Lee, w, Sacramento)
Feather River channel capacity (J. C. Blodgett, w, Sacramento)
Flood flows, Sacramento River (J. C. Blodgett, Sacramento)

Hydraulics, surface flow--Continued
Channel characteristics, California--Continued
Mokelumne River channel capacity (J. C. Blodgett, w, Sacramento)
Channel constrictions:
Alaska, scour research at bridge piers (V. M. Norman, w, Anchorage)
Bridge-site verifications, Louisiana (B. L. Neely, w, Baton Rouge)
Hydraulic criteria for design of bridges and culverts (K. W. Causseaux, w, Tuscaloosa, Ala.)
Hydraulic performance of bridges (B. E. Colson, w, Jackson, Miss.)
Verification of hydraulic techniques (W. J. Randolph, w, Nashville, Tenn.)
Flow characteristics:
Alluvial channel flow (C. F. Nordin, Jr., w, Fort Collins, Colo.)
Cooper River environmental study (F. A. Johnson, w, Columbia, S.C.)
Dispersion by turbulent flow in open channels (N. Yotsukura, w, W)
Dispersion processes in estuaries and rivers (H. B. Fischer, w, University of California, Berkeley)
Effect of temperature on winter runoff (W. D. Simons, w, M)
Floods from small drainages, California (A. O. Waananen, w, M)
Hydraulics of Port Royal Sound estuarine system (F. A. Johnson, w, Columbia, S.C.)
Mechanics of flow structure and fluid resistance—movable boundary (R. S. McQuivey, w, Bay St. Louis, Miss.)
Mechanics of fluid resistance (H. J. Tracy, w, Atlanta, Ga.)
Numerical simulation of hydrodynamic phenomena by digital computer (Chintu Lai, w, W)
Runoff model, Sacramento River, Calif. (J. C. Blodgett, w, Sacramento)
Time-of-travel and dispersion studies, North Carolina (W. G. Stamper, w, Raleigh)
Unsteady flow and saline intrusions in rivers and estuaries (R. A. Baltzer, w, W)
Laboratory studies:
Grain-size distribution and bedload transport (G. Williams, w, W)
Time-of-travel studies:
Indiana (R. E. Hoggatt, w, Indianapolis)
Maryland (K. R. Taylor, w, Parkville)
New Jersey (E. A. Postay, Trenton)
New York (L. A. Wagner, w, Albany)
See also Hydrologic instrumentation.

Hydrologic-data collection and processing:
Bathymetry and sediments, Rhode River estuary Anne Arundel County, Md. (A. Sinnott; R. L. Nace, w, W)
Drainage-area determinations:
Illinois (J. D. Camp, w, Champaign)
Indiana (R. E. Hoggatt, w, Indianapolis)
Kentucky (H. C. Beaber, w, Louisville)
Mississippi (J. M. Bettandorff, w, Jackson)
New Jersey, for gazetteer of streams (E. G. Miller, w, Trenton)
Tennessee (G. H. Wood, w, Nashville)

Hydrologic-data collection and processing--Continued
Hydrologic probability models (W. H. Kirby, w, W)
Rapid transmission and dissemination of current data (J. E. McCall, w, Trenton, N.J.)
River-mile determinations, South Carolina (W. T. Utter, w, Columbia)
Sediment loads in streams—methods used in measurement and analysis (J. V. Skinner, w, Minneapolis, Minn.)
Statistical inferences (E. J. Gilroy, w, W)
Water budget of North America (A. Wilson, w, W)
Water use data, 1970 (R. Murray, w, W)
Great Basin, selected hydrologic data (D. Price, w, Salt Lake City, Utah)
Florida, hydrologic suitability maps, Jacksonville (G. W. Leve, w, Jacksonville)
Kansas, computer storage, retrieval, and analysis of data (J. M. McNellis, D. V. Maddy, w, Lawrence)
Maryland, inventory and automation of well and pumping records (W. E. Webb, w, Parkville)
New York, Long Island, computer applications (D. E. Vaupel, w, Mineola)
Oregon, Portland harbor, scour at bridge piers (R. W. Childreth, w, Portland)
See also Hydrologic instrumentation.

Hydrologic instrumentation:
Borehole geophysics as applied to geohydrology (W. S. Keys, w, D)
Development of techniques for measurement of moisture-energy relationships in soils and vegetation (I. S. McQueen, w, D)
Electronic-equipment development—water (J. E. Eddy, w, W)
Instrumentation and environmental studies (G. E. Ghering, w, D)
Instrumentation research—water (H. O. Wires, w, Bay St. Louis, Miss.)
Laboratory research, instruments, water (G. F. Smoot, w, W)
Techniques of flood-plain mapping (G. W. Edelen, Jr., w, W)
See also Hydrologic-data collection and processing.

Hydrology, ground-water:
Geohydrologic environmental study (J. N. Payne, w, Baton Rouge, La.)
Geologic structure and fresh ground water in the Gulf Coastal Plain (P. H. Jones, w, Bay St. Louis, Miss.)
Geophysical logging research as applied to subsurface waste disposal (W. S. Keys, w, D)
Hydrogeology of carbonate rocks (V. T. Stringfield, w, W)
Hydrogic reconnaissance of geothermal areas in Oregon, Nevada, and California (F. H. Olmsted, w, M)
Hydrology of limestone and related rocks (F. A. Swenson, w, D)
Hydrology of Wilcox formation with reference to liquid waste emplacement in the Gulf Coastal Plain (P. H. Jones, w, Bay St. Louis, Miss.)
Organic aspects of deep-waste storage (R. L. Malcolm, w, D)
California, geothermal power, Long Valley (R. E. Lewis, Garden Grove)
Delaware, quantitative appraisal of Pleistocene aquifers (R. H. Johnston, w, Dover)

Hydrology, ground-water--Continued
Iowa:
Geohydrology of alluvial aquifer in vicinity of Red Rock Dam, Des Moines River (W. L. Steinhilber, w, Iowa City)
Hydrology of glaciated carbonate terranes (W. L. Steinhilber, w, Iowa City)
Kentucky, hydrologic factors relating to subsurface waste disposal (R. W. Davis, w, Louisville)
Minnesota, relation of ground water flow to lakes (R. J. Wolf, w, St. Paul)
New York:
Long Island:
Hydrologic effects of recharge basins (G. E. Seaburn, w, Mineola)
Hydrologic modeling (R. T. Getzen, w, Mineola)
Prediction of movement in zone of aeration (R. C. Prill, w, Mineola)
Suffolk County, hydrologic conditions (H. M. Jensen, w, Mineola)
Tennessee, Upper Duck River basin (C. R. Burchett, w, Nashville)
Wisconsin, a study of ground-water pollution in the Niagara dolomite of Door County, Wis. (M. G. Sherrill, w, Madison)
Hydrology, surface-water:
Arkansas, time-of-travel studies of Arkansas streams (T. E. Lamb, w, Little Rock)
California, infiltrometer studies (J. Limerinos, w, M)
Colorado, time-of-travel studies of Arkansas River (R. K. Livingston, w, D)
Florida, Loxahatchee River (H. G. Rodis, w, Miami)
Ohio, time-of-travel studies of Ohio streams (A. O. Westfall, w, Columbus)
Oklahoma, flow routing model of the North Canadian River between Canton Reservoir and Oklahoma City (D. B. Sapik, w, Oklahoma City)
North Carolina, upper Neuse River basin (A. L. Putnam, w, Raleigh)
Estuaries, South Carolina, reconnaissance studies (F. A. Johnson, w, Columbia)
Lakes and reservoirs:
Compilation of hydrologic data on lakes and reservoirs of Oregon (R. B. Sanderson, w, Portland)
California, flood hazard study (M. W. Busby, w, Garden Grove)
Florida, statewide, lake studies (G. H. Hughes, w, Tallahassee)
Missouri, small lakes (E. E. Gann, w, Rolla)
Nevada, bathymetric surveys of three Nevada lakes and reservoirs (F. C. Rush, w, Carson City)
Oregon, hydrologic inventory of Malheur Lake (L. L. Hubbard, w, Portland)
Washington, lakes of Washington (G. C. Bortleson, w, Tacoma)
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Streams:
Alaska, statewide stream discharge and (or) stage (H. Hulsing, w, Anchorage)
California, eastern San Gabriel hydrology (M. W. Busby, w, Garden Grove)
Hawaii, Oahu, hydrology and sedimentation in Moanalua Valley (G. Yamanaga, w, Honolulu)
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Illinois, Big Creek basin, effects of land-surface disposal of sewage effluent on streamflow, sedimentation, temperature, and specific conductance (C. R. Sieber, w, Champaign)
Massachusetts, Merrimack River estuary and Millers River, infrared imagery study (J. E. Cotton, w, Boston)
Mississippi, Pearl River boatway studies (J. K. Arthur, w, Jackson)
Missouri: Flood studies—small areas (L. D. Hauth, w, Rolla)
Storage requirements to control flood flows (J. Skelton, w, Rolla)
Stream and spring characteristics (J. Skelton, w, Rolla)
Nevada, small drainage areas, floods (L. Harmsen, w, Carson City)
New Hampshire, small streams (C. E. Hale, w, Boston, Mass.)
New York, influx to Lake Ontario (E. C. Rhodehamel, w, Albany)
Oregon, Alsea River basin, effects of logging on streamflow, sedimentation, and temperature (R. C. Williams, w, Bismarck, N.D.; D. D. Harris, w, Portland)
Pennsylvania, Philadelphia area (R. A. Miller, w, Harrisburg)
Tennessee, water resources of Center Hill Lake region (G. K. Moore, w, Nashville)
Wisconsin:
Effects of small impoundments on the interrelationships between aquatic biota and chemical quality of Nederlo Creek (P. A. Kammerer, w, Madison)
Hydrologic effects of a small reservoir, Nederlo Creek basin (P. A. Kammerer, w, Madison)
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Industrial minerals:
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Iron:
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Isotope ratios in rocks and minerals (I. Friedman, D)
Isotopic hydrology (F. J. Pearson, w, W)
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Land resources analysis:
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California, San Joaquin Valley (J. F. Poland, w, Sacramento)
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Cortez window and vicinity (J. D. Wells, D)
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Park City district (C. S. Bromfield, D)
Wisconsin, lead-zinc (W. S. West, Platteville)
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Microbial ecology of ground water (G. G. Ehrlich, w, M)
Solute balance, Abert and Summer Lakes, Oreg. (A. S. Van Denburgh, w, Carson City, Nev.)
Solute trends, Cold Spring playa lake, Nev. (A. S. Van Denburgh, w, Carson City)
Thermal and biological characteristics of lakes (R. G. Lipscomb, w, St. Louis, Mo.)
Colorado, determination of evaporation and thermal regime of selected Colorado lakes (J. F. Ficke, w, D)
New York:
Laboratory studies, bacteria symbiosis (P. E. Greeson, w, Albany)
Limnology of Oneida Lake (P. E. Greeson, w, Albany)
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Low flow and flow duration:
Georgia, statewide (R. F. Carter, w, Atlanta)
Indiana, low-flow characteristics (P. B. Rohne, w, Indianapolis)
Iowa, frequency studies (O. G. Lara, w, Iowa City)
Kansas, low flow in streams (P. R. Jordan, w, Lawrence)
Kentucky, low-flow characteristics (R. V. Swisshelm, w, Louisville)
Louisiana, low-flow frequency (R. A. Rohlf, w, Baton Rouge)
Massachusetts (G. K. Wood, w, Boston)
Minnesota, low-flow characteristics of Minnesota streams (T. G. Ross, w, St. Paul)
New Jersey, partial-record investigation (E. G. Miller, w, Trenton)
New York, low-flow frequency (F. L. Robison, w, Albany)
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South Carolina, low-flow characteristics, coastal plain (W. M. Bloxham, w, Columbia)
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Marine geology:
African shelf, Liberia (J. S. Schlee, Woods Hole, Mass.)
Atlantic Continental Shelf:
Geologic studies (J. S. Schlee, Woods Hole, Mass.)
Carolinas nearshore, geologic studies (M. Kane, Woods Hole, Mass.)
Gulf of Maine section, geologic studies (M. Kane, Woods Hole, Mass.)
Caribbean and Gulf of Mexico:
Bay of Campeche (G. W. Moore, La Jolla, Calif.)
Florida Continental Shelf gravity (H. L. Krivoy, Corpus Christi, Tex.)
Geochemistry of sediments (C. W. Holmes, Corpus Christi, Tex.)
Greater Antilles (L. E. Garrison, Corpus Christi, Tex.)
Tectonics, gulf (L. E. Garrison, Corpus Christi, Tex.)
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Maryland, effects of water quality changes on biota in estuaries (R. L. Cory, w, W)
New Jersey:
Recording of maximum tides (S. J. Stankowski, E. W. Moshinsky, w, Trenton)
Tidal stage, tide volumes (E. W. Moshinsky, w, Trenton)
Washington, influence of industrial and municipal wastes on estuarine and offshore water quality (W. S. Haushild, w, Tacoma)
Washington-Oregon, movement of radionuclides in the Columbia River estuary (D. W. Hubbell, w, Portland, Oreg.)
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Mercury:
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California, Coast Range ultramafic rocks (E. H. Bailey, M)
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Northern Wisconsin (C. E. Dutton, Madison)
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  - State resources (D. C. Duncan, W)
- Utah (W. B. Cashion, Jr., D)
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- Floras:
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North Coast limestone (E. V. Giusti)
Río Bucaná (G. D. Bennett)
San Juan area (H. R. Anderson)
South Coast alluvium analog model (G. D. Bennett)
Yabucoa area (T. M. Robinson, R. B. Anders)
Virgin Islands (w, San Juan, Puerto Rico, except as noted otherwise):
St. Croix (D. G. Jordan)
St. Thomas (D. G. Jordan, San Juan; O. J. Cosner, Richmond, Va.)
Alabama (w, Tuscaloosa):
Coosa River basin, upper part (J. R. Harkins)
East-central part (L. V. Causey)
Geology and hydrology along highway locations and rest areas (J. C. Scott)
Hydrogeologic study (J. G. Newton)
Piedmont area (J. C. Scott)
Relation of oil and gas industry to water resources (W. J. Powell)
Tennessee River basin (J. R. Harkins)
Tombigbee-Black Warrior River basin, upper part (J. R. Avrett)
Urban hydrology (R. C. Christensen)
Alaska (w, Anchorage, except as noted otherwise):
Ground water, statewide water levels (D. A. Morris)
Hydrology:
Anchorage area (W. W. Barnwell)

Water resources--Continued
Alaska--Continued
Hydrology--Continued
Greater Juneau Borough (J. A. McConaghy, Juneau)
Hydrologic environment of the trans-Alaska pipeline system (TAPS) (J. M. Childers)
Kenai Peninsula Borough (G. S. Anderson, S. H. Jones)
Municipal water-supply investigations (C. E. Sloan)
Water supplies for village schools (C. E. Sloan)
Arizona (w, Tucson, except as noted otherwise):
Regional ecological test site (H. H. Schumann, w, Phoenix)
Hydrogeologic reconnaissance of lower Tonto Creek basin (H. H. Schumann)
Ground water:
Analysis of water-level declines (E. B. Hodges)
Beardsley area (H. H. Schumann, w, Phoenix)
Big Sandy Valley (E. S. Davidson)
Coconino County, southern part (E. H. McGavock)
Navajo County, southern part (E. H. McGavock, w, Flagstaff)
Navajo Indian Reservation (M. E. Cooley)
Other Federal agency site studies (H. M. Babcock)
Reconnaissance studies of Lake Mead Recreational area, Arizona-Nevada (R. L. Laney, w, Phoenix)
Return flows—lower Colorado River (O. J. Loeltz, w, Yuma)
Safford area (E. S. Davidson)
Hydrology, alluvial basins (M. E. Cooley)
Arkansas (w, Little Rock):
Bayou Bartholomew systems study (M. E. Broom)
Ground-water hydrology of alluvial valleys of Arkansas and Verdigris Rivers (M. S. Bedinger)
California (w, M, except as noted otherwise):
Artificial recharge (J. A. Moreland, w, Garden Grove)
Circulation patterns and sediment transport in San Francisco Bay and adjacent ocean (T. J. Conomos)
Computer technology in water-resources studies:
Dispersion of heat in stratified flow (J. G. Weil)
Modeling and simulation of surface-water quality (S. M. Zand)
Reservoir yield and bank storage relationships—computer applications (T. H. Thompson)
Geochemistry of water, chemical reactions at mineral surfaces (J. D. Hem)
Ground water:
Antelope Valley area (G. A. Miller, Garden Grove)
Appraisal (Robert Faye)
Aquicludes in San Joaquin Valley (G. L. Bertoldi, Sacramento)
Barstow area, continuing inventory (J. H. Koehler, Garden Grove)
City of Modesto, ground-water planning (R. W. Page, Sacramento)
Death Valley National Monument hydrologic reconnaissance (G. A. Miller, Garden Grove)
Evaluation (J. A. Moreland, Garden Grove)
Geohydrology of Pajaro Valley (J. P. Akers)
Hollister-San Juan Bautista area (C. Kilburn)
Irvine Ranch, artificial recharge (J. A. Singer, Garden Grove)
Madera area (W. R. Hotchkiss, Sacramento)
Water resources--Continued
California--Continued
Ground water--Continued
Network analysis (L. C. Dutcher)
Palo Verde Valley (W. R. Moyle, Jr., Garden Grove)
Pumpage, Monterey County (K. S. Muir)
Pumpage, part of San Joaquin Valley (H. T. Mitten, Sacramento)
Quality degradation, Barstow area (J. L. Hughes, Garden Grove)
Stanislaus County (R. W. Page, Sacramento)
Suisun Bay area (C. Kilburn)
Upper Coachella Valley, artificial recharge (S. J. Tyley, Garden Grove)
Wastewater infiltration (G. L. Bertoldi, Sacramento)
Hydrology:
Characteristics of California lakes (J. R. Crippen)
Oak Glen water resources development (R. E. Lewis, Garden Grove)
Perris Valley urban hydrology (M. Busby, Garden Grove)
Relation between surface water and ground water, factors determining feasibility of artificial recharge (J. Rubin)
Sacramento Valley hydrology (R. W. Page, Sacramento)
Surface water:
Characteristics of California lakes (R. C. Averett)
Lopez reservoir water quality (R. C. Averett)
Temperature distribution in natural streams (J. C. Blodgett, Sacramento)
Water quality:
Dwinnell reservoir (Alex Dong, Sacramento)
Ground-water (J. W. Warner, Garden Grove)
Lompoc Valley salt balance (G. A. Miller, Garden Grove)
Colorado (w, D, except as noted otherwise):
Ground water:
Baca and southern Prowers Counties (P. A. Emery)
High Plains of Colorado (W. E. Hofstra)
Leadville Limestone yields large quantities of water near McCoy (E. R. Hampton)
Pueblo Army Depot (F. A. Welder)
Western Colorado (E. R. Hampton)
Hydrology:
Arkansas River valley, Leadville to State line (P. A. Emery)
Black Squirrel Valley, El Paso County (D. L. Bingham)
Piceance Creek basin (J. F. Ficke)
Rocky Mountain Arsenal (R. Brennan)
San Luis Valley (P. A. Emery)
South Platte River basin, Henderson to State line (R. T. Hurr)
Rocky Mountain National Park (J. E. Biesecker)
Upper Arkansas River basin (P. A. Emery, L. A. Hershey, Pueblo)
Connecticut (w, Hartford):
Ground-water hydrology, southeastern Connecticut (R. L. Melvin)
Part 5, Lower Housatonic River basin (W. E. Wilson)
Part 6, Upper Housatonic River basin (M. A. Cervione, Jr.)
Part 7, Upper Connecticut River basin (R. B. Ryder)
Part 8, Quinnipiac River basin (G. R. Tarver)
Part 9, Farmington River basin (H. T. Hopkins)

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- Connecticut--Continued
  - Part 10, lower Connecticut River basin (L. A. Weiss)
  - Surface-water hydrology, Hollenbeck River basin (F. R. Ruggles)
  - Urban hydrology (J. A. Baker)
- Florida (w, Tallahassee, except as noted otherwise):
  - Geohydrology, Cocoa well-field area (J. M. Frazee, Jr., Winter Park)
  - Ground water:
    - Dade County, special studies (F. W. Meyer, Miami)
    - Fort Lauderdale area, special studies (H. J. McCoy, Miami)
    - Hallandale area, (H. W. Bearden, Miami)
    - Hollywood area (H. W. Bearden, Miami)
    - Peace and Alafia River basins (A. F. Robertson, Tampa)
    - Sarasota County, shallow aquifer (H. Sutcliffe, Sarasota)
    - Southwestern Hillsborough County (J. W. Stewart, Tampa)
  - Hydrobiology:
    - Big Cypress (H. Klein, Miami)
    - Conservation Area 3 (B. F. McPherson, Miami)
  - Hydrology:
    - Analog model, Biscayne aquifer (E. H. Cordes, Miami)
    - Aquifer modeling, Hillsborough, Pasco, Pinellas Counties (A. F. Robertson, Tampa)
    - Effects of canal controls (W. A. J. Pitt, Miami)
    - Infiltration, Miami Canal (F. W. Meyer, w, Miami)
    - Model study, Hillsborough River basin (J. F. Turner, Jr., Tampa)
    - Salinity of lower Withlacoochee River (G. L. Faulkner, Ocala)
  - Remote sensing:
    - Alafia and Peace basins (A. E. Coker, Tampa)
    - Applications (A. E. Coker, Tampa)
    - Everglades area (A. L. Higen, Miami)
  - Special studies, statewide (C. S. Conover, R. W. Pride)
  - Surface water, hydrologic study, Lake Thonotosassa (J. D. Hunn, Tampa)
  - Water atlas (A. A. Garrett)
  - Water use:
    - Desoto County (W. E. Wilson, Tampa)
    - Statewide (R. W. Pride)
  - Broward County (C. B. Sherwood, w, Miami)
  - City of Pensacola (H. Trapp, Jr.)
  - Clearwater-Dunedin area (R. N. Cherry, Tampa)
  - Desoto-Hardee Counties (W. E. Wilson, Tampa)
  - Duval County (G. W. Leve, Jacksonville)
  - East-central Florida (F. A. Watkins, Winter Park)
  - Everglades National Park (A. L. Higer, Miami)
  - Indian River County (J. O. Kimrey, Winter Park)
  - Lee County (D. H. Boggess, Ft. Myers)
  - Marion County (G. L. Faulkner, Ocala)
  - Osceola County (J. M. Frazee, w, Winter Park)
  - Palm Beach County (H. G. Rodis, Miami)
  - Seminole County (C. H. Tibbals, Winter Park)
  - South Florida ecological study (H. Klein, Miami)
  - Tampa Bay area (C. R. Goodman, Tampa)
  - Tampa Bypass Canal area (L. H. Motz, Tampa)
  - Walton County (C. A. Pascale)
  - Western Collier County (H. J. McCoy, Miami)

Water resources--Continued
- Georgia (w, Atlanta):
  - Availability of water supplies in northwest Georgia (C. W. Cressler)
  - Ground water:
    - Colquitt County (E. A. Zimmerman)
    - Gordon, Murray, and Whitfield Counties (C. W. Cressler)
    - Liberty and McIntosh Counties (R. E. Krause)
  - Hydrologic appraisal of the upper Cretaceous (R. C. Vorhis)
  - Hydrology, Liberty County, Newport River estuaries (T. R. Dyar)
  - Information system (J. R. George)
  - Quality of ground water (R. G. Grantham)
- Georgia, Florida, and South Carolina, study of the principal limestone aquifer, Suwannee Strait, in part (S. M. Herrick, w, Atlanta, Ga.)
- Hawaii (w, Honolulu):
  - Hawaii, water-resources reconnaissance summary (D. A. Davis)
  - Maui, central part, reconnaissance (K. J. Takasaki)
  - Oahu, Pearl Harbor area, hydrology of basal-water systems (R. H. Dale)
- Idaho (w, Boise):
  - Hydrologic environment, White Clouds area (W. W. Emmett)
  - Hydrologic reconnaissance, Pahsimeroi River basin (H. W. Young)
  - Leakage from Blackfoot Reservoir (N. P. Dion)
  - Little Lost River basin (H. A. Waite, S. O. Decker)
  - Observation-well network, Kootenai Flats (N. P. Dion)
  - Recharge to Rathdrum Prairie (R. E. Hammond)
  - Test drilling, Snake River Plain (E. G. Crosthwaite)
- Indiana (w, Indianapolis):
  - Analog model, upper White River basin (R. W. Maclay)
  - Maumee River basin (R. A. Pettijohn)
  - Middle Wabash River basin (J. R. Marie)
  - St. Joseph River basin (J. P. Reussow)
- Iowa (w, Iowa City):
  - Ground-water resources of a Mississippian aquifer (W. L. Steinhilber)
  - South-central (J. W. Cagle, Jr.)
  - Water availability, Muscatine Island, Muscatine County (R. E. Hansen)
- Kansas (w, Lawrence, except as noted otherwise):
  - Ground water:
    - Ford and Hodgman Counties (H. E. McGovern, Garden City)
    - Gove, Logan, Wallace Counties (E. D. Jenkins, Colby)
    - Great Bend Prairie, south-central Kansas (C. K. Bayne)
    - Greeley and Wichita Counties (E. D. Jenkins, Colby)
    - Hamilton County (H. E. McGovern, Garden City)
    - Montgomery County (H. G. O'Connor)
    - Nemaha County (J. R. Ward)
    - Northwestern part (E. D. Jenkins, Colby)
    - Rush County (J. M. McNellis)
    - Scott and Lane Counties (H. E. McGovern, Garden City)
    - Southwestern part (H. E. McGovern, Garden City)
    - Washington County (H. G. O'Connor)

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Kansas--Continued
Kansas Valley—Junction City to Kansas City (S. W. Fader)
Land subsidence near oil and gas wells (S. W. Fader)
Numerical modeling of Little Arkansas River basin, south-central Kansas (J. C. Halepaska, D. B. Richards)
Saline ground-water resources of Kansas (K. M. Keene)
Kentucky (w, Louisville):
Bowling Green area (T. W. Lambert)
Covington-Lexington-Louisville triangle (D. S. Mull)
Elizabethtown area (T. W. Lambert)
Ground water:
Alluvium of major Ohio River tributary streams (P. D. Ryder)
Hydrology of buried Pennsylvanian channel sandstone (R. W. Davis)
Mammoth Cave area (R. V. Cushman)
Louisiana (w, Baton Rouge, except as noted otherwise):
Ground water:
Geohydrology of Evangeline and Jasper aquifers, southwestern part (M. S. Whitfield)
Gramercy area (C. Kilburn)
Hydrology of the Red River Valley (A. H. Ludwig, Little Rock, Ark.)
Kisatchie Forest area (J. E. Rogers)
Morehouse Parish (T. H. Sanford)
Norco area (R. L. Hosman)
Ruston area (T. H. Sanford)
Terrace aquifer, central Louisiana (T. H. Sanford)
Water quality in upper Mississippi River Delta alluvium (M. S. Whitfield)
Reports on special topics (M. F. Cook)
Site studies (R. L. Hosman)
Southwestern part (A. L. Zack)
Surface water:
Temperature of water in Louisiana streams (A. J. Calandro)
Velocity of Louisiana streams (A.,J. Calandro)
Tangipahoa-Tchefuncte River basins (D. J. Nyman)
Amite-Tickfaw River basins (M. D. Winner, Jr.)
Baton Rouge area (C. D. Whiteman, Jr.)
New Orleans area (C. D. Whiteman, Jr.)
Maine (w, Augusta):
Ground water:
Cherryfield-Jonesboro area (G. C. Prescott)
Meduxnekeag and Prestile basins in Maine (G. C. Prescott)
St. John basin in Maine (G. C. Prescott)
Maryland (w, Parkville, except as noted otherwise):
Ground water:
Aquifer modeling of coastal plain, feasibility and planning (E. G. Otton)
Aquifer research in limestone terranes, Frederick and Hagerstown Valleys (L. J. Nutter)
Aquifer studies in the Triassic rocks (L. J. Nutter)
Evaluation of Magothy aquifer Annapolis area (F. K. Mack, Annapolis)
Geohydrology of northeastern Worcester County (J. M. Weigle)
Georges Creek basin, a corner of Appalachia (D. O'Bryan, W)

Water resources--Continued
Massachusetts (w, Boston):
Ground water:
Boston, central area (J. E. Cotton)
Cape Cod National Seashore (J. E. Cotton)
Charles River basin (E. H. Walker)
Connecticut River lowlands (E. H. Walker)
Deerfield-Hoosic River basins (L. G. Toler)
Mathematical modeling of Ipswich River basin (I. James)
Nashua River basin (R. A. Brackley)
Neponset-Weymouth River basins (R. A. Brackley)
Northeastern coastal basins (F. B. Gay)
Quality-of-water surveillance (L. G. Toler)
Southeastern coastal drainage (J. R. Williams)
Water and related land resources for southeastern New England (M. H. Frimpter)
Michigan (w, Lansing):
Ground water:
Baraga County (G. E. Hendrickson)
Marquette County (G. E. Hendrickson)
Northern Marquette County (C. J. Doonan)
Pictured Rocks National Lakeshore (C. J. Doonan)
Hydrology of river-based recreation (G. E. Hendrickson)
River basins in southeastern Michigan (R. L. Knutilla)
Surface water, effect of glacial deposits on streamflow (P. C. Bent)
Washtenaw County (F. R. Twenter)
Minnesota (w, St. Paul):
Ground water for irrigation near Appleton (S. P. Larson)
Ground water for irrigation near Alexandria (M. S. McBride)
Hydrology, Twin Cities metropolitan area (R. F. Norvitch)
Water budget:
Eagle Lake (R. J. Wolf)
Lake Sallie (W. B. Mann IV)
Shagawa Lake (D. W. Ericson)
Water-resources reconnaissance of watershed units:
Big Fork River (J. O. Helgesen)
Blue Earth River (H. W. Anderson, Jr.)
Cannon River (H. W. Anderson, Jr.)
Cottonwood River (H. W. Anderson, Jr.)
Crow River (G. F. Lindholm)
Kettle River (G. F. Lindholm)
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Lower Minnesota River (H. W. Anderson, Jr.)
Lower St. Croix River (G. F. Lindholm)
Mississippi River-Sauk River (G. F. Lindholm)
Rum River (G. F. Lindholm)
Snake River (G. F. Lindholm)
Zumbro River (H. W. Anderson, Jr.)
Mississippi (w, Jackson):
Alcorn, Itawamba, Prentiss, and Tishomingo Counties (B. E. Wasson)
Benton, Lafayette, Marshall, Pontotoc, Tippah, and Union Counties (R. Newcome)
Calhoun, Chickasaw, Choctaw, Montgomery, Webster, and Yalobusha Counties (R. E. Taylor)
Copiah-Simpson Counties (R. Newcome)
Ground-water, delineation of saline ground water in State (G. J. Dalsin)
Harrison County (J. A. Callahan)
Jackson County (D. E. Shattles)

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- Mississippi--Continued
  - Kemper, Leake, Neshoba, Noxubee, and Winston Counties (R. E. Taylor)
  - Surface water, low-flow analysis of Mississippi streams (E. J. Tharpe)
- Missouri (w, Rolla):
  - Greene County (L. F. Emmett)
  - South-central Missouri (E. E. Gann)
  - St. Louis, St. Charles, and Jefferson Counties (H. G. Jeffery)
  - West-central Missouri (E. E. Gann)
- Montana (w, Billings, except as noted otherwise):
  - Ground water:
    - Central Powder River valley (W. R. Miller)
    - Clark Fork basin (A. J. Boettcher)
    - Eastern Montana (W. B. Hopkins)
    - Helena valley (K. B. Wilke, D. L. Coffin)
    - Missoula valley (A. J. Boettcher)
    - Northern Cheyenne Indian Reservation (W. B. Hopkins)
    - Northern Judith basin (R. D. Feltis)
    - Rock Creek valley (A. J. Boettcher)
    - Southern Powder River valley (W. R. Miller)
    - Statewide, observation well measurements (T. E. Reed)
    - Water supplies for national parks, monuments, and recreation areas (R. D. Feltis, Billings; D. L. Coffin, Helena)
    - Wiota-Wolf Point Irrigation Unit (W. B. Hopkins)
- Nebraska (w, Lincoln):
  - Ground water, determination of ground-water withdrawals in Hamilton, York, Seward, and Clay Counties (E. K. Steele)
  - Observation-well program, ground water of Boyd County (C. F. Keech)
  - Stream-gaging program:
    - Characteristics of streamflow at gaging stations in Shell Creek, Elkhorn River, and Salt Creek basins (F. B. Shaffer)
    - Floods of 1971 (F. B. Shaffer)
  - Water-quality investigations, selenium in ground water (R. A. Engberg)
  - Water in the Long River basin (R. Bentall)
  - Pierce County (C. F. Keech)
  - Seward County (M. J. Ellis)
- Nevada (w, Carson City):
  - Carson River basin (P. A. Glancy, T. L. Katzer)
  - Fish Lake Valley (F. E. Rush, T. L. Katzer)
  - Ground water:
    - Great Basin (T. E. Eakin)
  - Las Vegas Valley (J. R. Harrill)
  - Lemmon Valley (J. R. Harrill)
  - Railroad and Penoyer Valleys (A. S. Van Denburgh, F. E. Rush)
  - Smith Valley (F. E. Rush)
  - Truckee River basin (A. S. Van Denburgh, R. D. Lamke)
  - Water supply, mining districts (H. A. Shamberger)
- New Jersey (w, Trenton):
  - Ground water:
    - Camden County, geology and ground-water resources (G. M. Farlekas)
    - Geohydrologic analysis of the Englishtown Formation, New Jersey (W. D. Nichols)

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- New Jersey--Continued
  - Ground water--Continued
    - Geohydrologic analysis of the Mount Laurel—Wenonah Formations (B. Nemickas)
    - Geohydrology, Potomac-Raritan-Magothy aquifer system—Trenton to Perth Amboy (G. M. Farlekas)
    - Geohydrology, Potomac-Raritan-Magothy aquifer system—Trenton to Salem (H. E. Gill, G. M. Farlekas)
    - Water-level fluctuations, 1963—67 (J. H. Nakao)
    - Wharton Tract (E. C. Rhodehamel)
  - Ground-water use inventory (W. Kam)
  - Hydrologic investigation, effects of regional sewers on streamflow (E. G. Miller)
- New Mexico (w, Albuquerque, except as noted otherwise):
  - Ground and surface water:
    - Elephant Butte marsh (T. E. Kelly)
    - Mescalero Peat (F. P. Lyford, Roswell)
    - Project planning Las Cruces area (C. A. Wilson, Las Cruces)
    - Santa Fe County (W. A. Mourant)
  - Ground water:
    - Availability, White Sands Missile Range (T. E. Kelly)
    - Boreholes, White Sands Missile Range (J. B. Cooper)
    - Capitan Reef (W. L. Hiss)
    - Gallup-Tohatchi area (J. B. Cooper)
    - Grant County (F. D. Trauger)
    - Harding County (F. D. Trauger)
    - Malaga Bend area (J. S. Havens)
    - Mimbres basin (J. S. McLean)
    - Miscellaneous activities, Bureau Mines (W. A. Mourant)
    - Miscellaneous activities, State Engineer (J. B. Cooper)
    - Northern high plains (E. G. Lappala)
    - Rio Grande basin (T. E. Kelly)
    - Roswell basin, Chaves and Eddy Counties, quantitative analysis of the ground-water system (G. E. Welder)
    - Special problems (J. B. Cooper)
    - Study plan for missile complexes (W. E. Hale)
    - Taos-Cerro area (F. C. Koopman)
    - White Sands Missile Range, water levels and pumpage (J. A. Basler)
  - Ground-water stations (J. D. Hudson)
  - Hydrologic investigations:
    - Data bank (J. B. Peterson)
    - Gila River (J. D. Hudson)
    - San Juan River valley (F. P. Lyford)
  - State water plan (J. B. Cooper)
  - Surface water:
    - Rio Grande compact (E. D. Cobb)
    - River basin analysis (E. D. Cobb)
    - Surface-water stations (L. J. Reiland, Santa Fe)
- New York (w, Albany, except as noted otherwise):
  - Ground water:
    - Long Island:
      - Bay Park, artificial recharge of treated sewage (J. Vecchioli, Mineola)
      - Nassau County, ground-water system study (N. M. Perlmutter, Mineola)
      - Nassau County, "right-of-way" for recharge wells (H. F. Ku, Mineola)

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Ground water--Continued
Long Island--Continued
Suffolk County, effect of solid-waste disposal sites on ground-water quality (G. E. Kimmel, Mineola)
Suffolk County, geochemical aspects of pollution, Babylon-Islip (J. Soren, Mineola)
Suffolk County, hydrologic conditions (H. M. Jensen, Mineola)
Suffolk County, water-quality observation well program (J. Soren, Mineola)
Long Island:
Basic hydrologic data (D. E. Vaupel, Mineola)
Central, effect of recharge basins (G. W. Seaburn)
Computer applications (D. E. Vaupel, Mineola)
Hydrologic modeling (G. T. Getzen, Mineola)
Preliminary evaluation of quality of water (C. A. Harr, Mineola)
North Carolina (w, Raleigh):
Ground water:
Blue Ridge Parkway (C. E. Simmons)
Cape Hatteras National Seashore (M. D. Winner)
Hydrology of fractured rocks (R. C. Heath)
Northeastern part of State (K. L. Lindskov)
Public water supplies (N. M. Jackson)
Surface water:
Hydrology of estuaries (H. B. Wilder)
Low-flow and water-availability studies (H. G. Hinson)
North Dakota (w, Bismarck):
Ground water:
Benson and Pierce Counties (P. G. Randich)
Bowman and Adams Counties (M. G. Croft)
Cavalier and Pembina Counties (R. D. Hutchinson)
Dunn County (R. L. Klausing)
Emmons County (C. A. Armstrong)
Grant and Sioux Counties (P. G. Randich)
Griggs and Steele Counties (C. A. Armstrong)
McLean County (R. L. Klausing)
Mercer and Oliver Counties (M. G. Croft)
Nelson and Walsh Counties (J. S. Downey)
Stark and Hettinger Counties (H. Trapp, Jr.)
Ohio (w, Columbus):
Ground water:
Availability in Circleville area (R. E. Fidler)
Northeastern part, principal aquifers (A. C. Sedam)
Southeastern part, principal aquifers (A. C. Sedam)
Southwestern and central parts, principal aquifers (S. E. Norris)
Oklahoma (w, Oklahoma City):
Ardmore and Sherman quadrangles, south-central Oklahoma (D. L. Hart, Jr.)
Clinton quadrangle, west-central Oklahoma (J. E. Carr)
Enid quadrangle, north-central Oklahoma (R. H. Bingham)
Ground water:
Hydrogeology of the Arbuckle Group in the Wichita Mountains area, south-western Oklahoma (J. S. Havens)
Hydrology of alluvial valleys of Arkansas and Verdigris Rivers (M. S. Bedinger, Little Rock, Ark.)
Interpretation of records and requests (J. H. Irwin)
Upper Red River basin, above Denison Dam, Oklahoma and Texas (D. B. Sapik)

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Oklahoma--Continued
Hydrology:
Oklahoma panhandle (D. L. Hart, Jr., G. L. Hoffman)
Platt National Park (D. L. Hart, Jr.)
Lawton quadrangle, southwestern Oklahoma (J. S. Havens)
McAlester and Texarkana quadrangles, southeastern Oklahoma (M. V. Marcher)
Oklahoma City quadrangle, central Oklahoma (R. H. Bingham)
Woodward quadrangle, northwest Oklahoma (R. B. Morton)
Oklahoma and Kansas, ground water, Middle Arkansas, Verdigris, and Grand River basins (S. W Fader, Lawrence; R. B. Morton, Oklahoma City)
Oregon (w, Portland):
Ground water:
Coos Bay, dune aquifers (J. H. Robison)
Corvallis-Albany area (F. J. Frank)
Grants Pass, availability (J. H. Robison)
Klamath River Basin, appraisal (A. R. Leonard)
Lower Santiam River basin (D. Helm)
Northern Clackamas County (A. R. Leonard)
Surface water, velocity fluctuations in Columbia River (L. L. Hubbard)
Pennsylvania (w, Harrisburg, except as noted otherwise):
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