The Alaska Mineral Resource Assessment Program: Guide to Information Contained in Folio of Geologic and Mineral Resource Maps of the Philip Smith Mountains Quadrangle, Alaska

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ABSTRACT

The geology and mineral resources of the Philip Smith Mountains quadrangle were virtually unexplored until the investigations for oil began in northern Alaska. Construction of the Trans-Alaskan Pipeline System has now made the quadrangle accessible by road. In 1975 and 1976 a team of geologists, geochemists, and geophysicists investigated the quadrangle in order to assess its mineral resource potential. This report is a guide to the resulting folio of twelve maps that describe the geology, stream sediment geochemistry, aeromagnetic features, Landsat imagery, and mineral resources of the area.

The bedrock geology and aeromagnetic surveys show that mineral deposits associated with intrusive rocks are probably absent. However, the geology and geochemical anomalies do indicate the possibility of vein and strata-bound deposits of copper, lead, and zinc in the Paleozoic shale and carbonate rocks in the southern part of the quadrangle and of strata-bound deposits of zinc and copper in the Permian and Mesozoic shales along the mountain front. The northwestern part of the quadrangle has a low to moderate potential for oil or gas; Mississippian carbonate rocks are the most likely reservoir. The only minerals produced to date have been construction materials.

INTRODUCTION

PURPOSE AND SCOPE

This circular and a separate folio of related maps are intended to provide information about the mineral resources of the Philip Smith Mountains quadrangle. The set of publications is one of a series of individual quadrangle reports prepared under the auspices of the Alaska Mineral Resource Assessment Program (AMRAP) in order to provide information for use in planning a national minerals policy and in making government and private decisions about land-use and minerals exploration and development.

The Philip Smith Mountains quadrangle was selected for assessment because it lies on the projected trend of areas that were found favorable for mineral resources in the adjacent Chandalar quadrangle (DeYoung, 1978) and it has been relatively unexplored. The recent completion of the Trans-Alaskan pipeline and the James W. Dalton Highway has greatly improved access to the quadrangle.

The folio comprises twelve individually available quadrangle maps that show the geology and telegeology, the geochemical and aeromagnetic data, and the areas favorable for mineral resources (see table 1). These are reconnaissance maps; the 1:250,000 scale is compatible with the low density of the field observations, which were designed to provide information rapidly and uniformly over a large and little-known region.

GEOGRAPHY AND ACCESS

The Philip Smith Mountains quadrangle is an area of about 13,600 km² in northern Alaska between latitudes 68° N. and 69° N., and longitude 147° W. and 150° W. (fig. 1). The Endicott and Philip Smith Mountains of the Brooks Range occupy all but the northwestern quarter of the quadrangle and include the Continental Divide, which crosses the quadrangle diagonally from southwest to northeast (fig. 2).

The mountains, which have been glaciated recently, are generally steep and narrow crested, rising about 1,000 m above the flat valley floors. Cirques and small alpine glaciers are common near the Continental Divide, particularly near the center of the quadrangle where the two highest peaks reach an elevation of 2,446 m. Along the south edge of the quadrangle, the mountains are more subdued and rounded, and at the north front of the range, they slope down abruptly to the Arctic Foothills, which in this area are gently sloping plains covered by glacial deposits with only a few bedrock hills.

The Sagavanirktok River and its tributaries drain most of the quadrangle north of the divide

TABLE 1. *Component maps and reports of the Philip Smith Mountains quadrangle mineral resource assessment.*

Report	Subject
U.S. Geological Survey Miscellaneous Field Studies (MF) Maps:	
MF-879A (Hamilton, 1978)	Surficial geology.
MF-879B (Brosgé and others, 1979)	Bedrock geology.
MF-879C (Menzie II and others, 1983)	Mineral resources other than oil and gas.
MF-879D (Bird, 1983)	Oil and gas resources.
MF-879E (Cady, 1978)	Aeromagnetic contours and interpretation.
MF-879F (Le Compte, 1979)	Interpretation of Landsat imagery.
MF-879G (Cathrall and others, 1978a)	Copper in stream sediment.
MF-879H (Cathrall and others, 1978b)	Lead in stream sediment.
MF-879I (Cathrall and others, 1978f)	Zinc in stream sediment.
MF-879J (Cathrall and others, 1978c)	Silver in stream sediment.
MF-879K (Cathrall and others, 1978d)	Barium in stream sediment.
MF-879L (Cathrall and others, 1978e)	Antimony, arsenic, bismuth, cadmium, molybdenum and tin in stream sediment.
U.S. Geological Survey Open-File (OF) Reports:	
OF-77-223 (Detra, 1977)	Delineation of anomalous lead-zinc area.
OF-77-244 (Cathrall and others, 1977b)	Geochemical analyses of stream sediment.
OF-77-426 (Cathrall and others, 1977a)	Geochemical analyses of heavy mineral concentrates from stream sediment.
OF-78-559 (Dutro and Detra, 1978)	Geochemical analyses of the Hunt Fork Shale.
U.S. Geological Survey Circular:	
Circ. 772-B (Dutro, 1978)	Potential strata-bound lead-zinc mineralization.

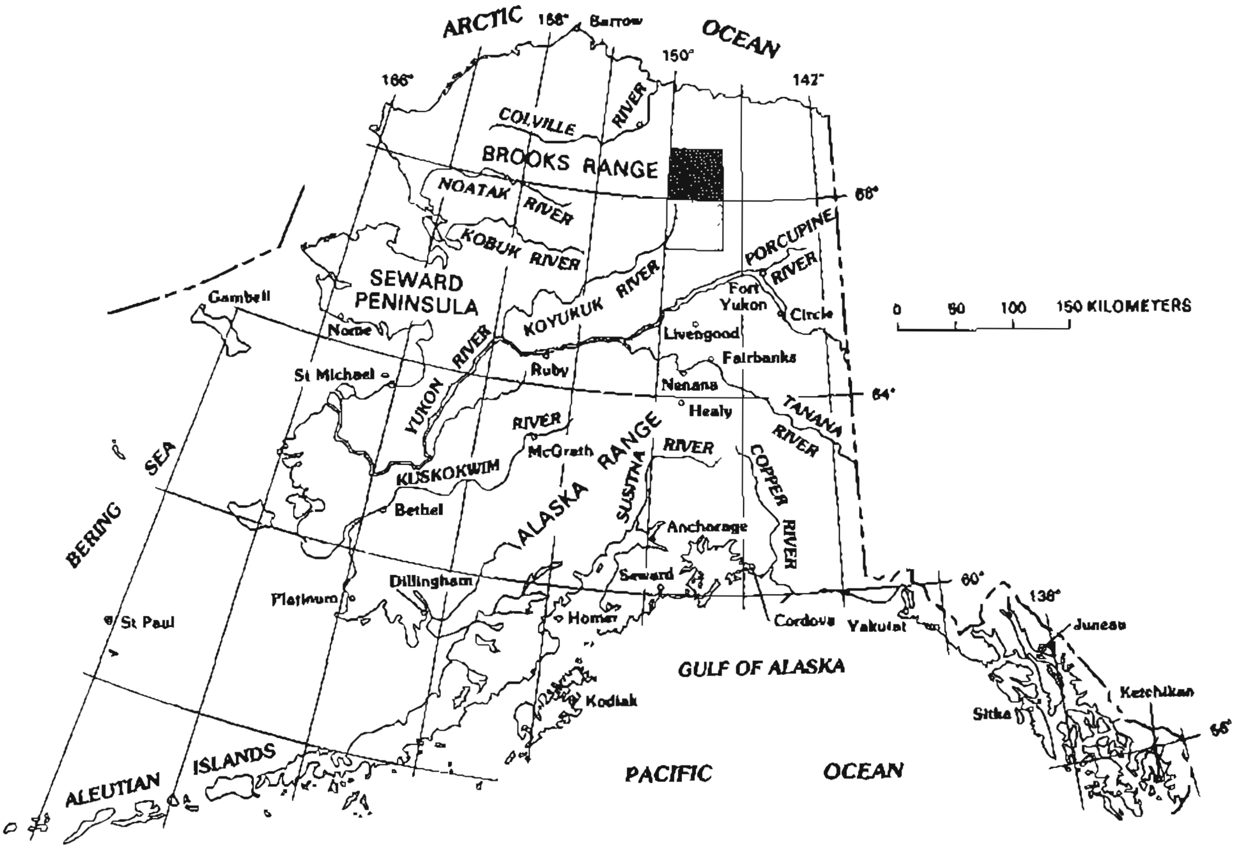

FIGURE 1.—Index map of Alaska showing location of Philip Smith Mountains quadrangle (dark shading) and Chandalar quadrangle (light shading).

and flow into the Arctic Ocean near Prudhoe Bay. The northwestern part of the quadrangle is drained by the Itkillik River, which heads against the Continental Divide west of the quadrangle, and by the Kuparuk and Toolik Rivers, which head against the mountain front. On the south side, the Dietrich River, whose valley is occupied by the James W. Dalton Highway, drains a small area in the extreme southwest corner of the quadrangle. The Dietrich River is a tributary of the Koyukuk, but all the other south-flowing rivers are tributaries of the Chandalar. The largest of these tributaries is the Wind River, in the southeast part of the quadrangle. None of these rivers is easily navigable.

Two low passes in the western part of the quadrangle, at an elevation of about 1,450 m, lie at the heads of tributaries of the North Fork of the Chandalar and the Dietrich Rivers. An unnamed pass is at the head of the Wind River in the east. In the center of the quadrangle, the Middle Fork of the Chandalar and all its tributaries head in

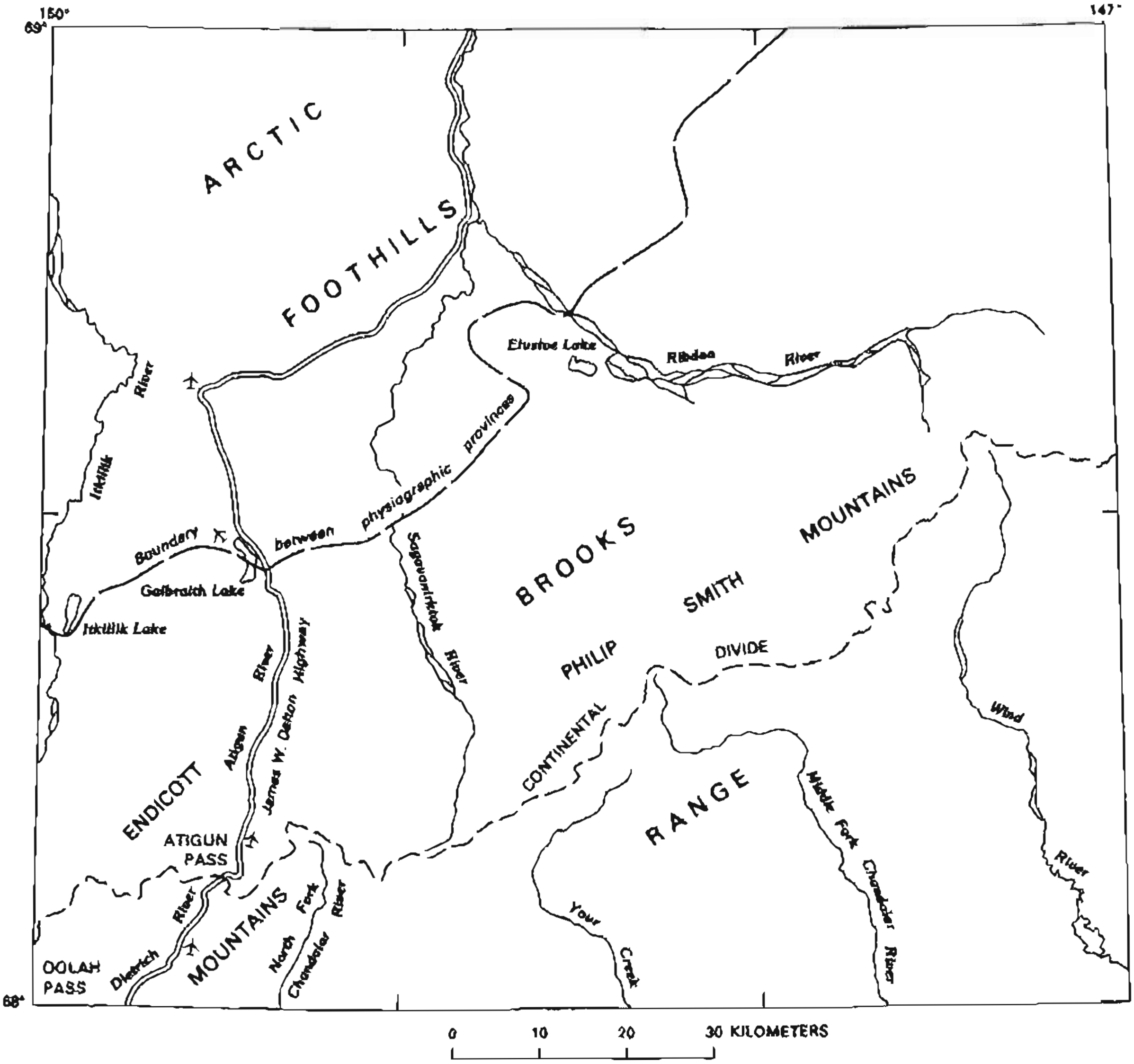

FIGURE 2.—Philip Smith Mountains quadrangle showing location of Arctic Foothills and Brooks Range physiographic provinces, the James W. Dalton Highway, and large airstrips (airplane symbols). Only the Galbraith Lake airstrip is maintained.

glaciers and steep canyons, and there are no passes for a distance of about 60 km along the divide.

The James W. Dalton Highway, built for the Trans-Alaskan pipeline, gives access to the quadrangle by way of the Dietrich River and a tributary of the North Fork of the Chandalar River, south of the divide; Atigun Pass; and the Atigun and Sagavanirktok Rivers north of the divide. The highway connects with Fairbanks to the south and with Prudhoe Bay to the north. Adjacent to the road, four private airstrips, 760-1,580 m in length, are suitable for heavy aircraft. As of March 1981, the largest of these, at Galbraith Lake, was maintained but access was limited. The other airstrips were closed and were not maintained (fig. 2). Away from the highway, two large lakes at the north front of the range and several smaller lakes at and south of the continental divide provide landing places for float planes in the summer and wheel or ski planes in the winter. In addition, most of the rivers flow through gravel bars and terraces that may provide suitable landing places for light airplanes.

ACKNOWLEDGMENTS

Fieldwork in the northern part of the quadrangle in 1949-51 was entirely supported by the U.S. Navy as part of the investigation of Naval Petroleum Reserve No. 4. Studies of surficial geology by Hamilton in 1969-71 were carried out during his employment as a consultant to the Alyeska Pipeline Service Company. This organization later (1975-76) supplied meals, lodging, office space, and helicopter fuel at their Galbraith Lake camp for U.S. Geological Survey field crews. Without the facilities provided by the pipeline camp, field operations would have been far more difficult and costly.

The bedrock geological work for the AMRAP investigation was done by R. L. Detterman, J. T. Dutro, Jr., N. J. Silberling, and the authors. S. P. Marsh lent his experience to help with the geochemical sampling in the adjacent Chandalar quadrangle. David E. Detra, Martha Miller-Hoare, William B. Maze, David M. Orchard, Margo I. Toth, and R. M. Thorson gave valued assistance in the field and office. Miles L. Silberman made the potassium-argon age determinations. Chemical analyses were done by E. F. Cooley, J. A. Dupree, J. T. Hurrell, R. L. Hutchens, R. M. O'Leary and P. A. Svendsen, and statistical analyses of data were done by T. M. Billings, S. K. McDanal, and C. M. Dougal.

MINERAL EXPLORATION AND PRODUCTION

Schrader (1904), in his description of the gold resources of the upper Koyukuk River, stated that prospectors had reported finding placer gold on the Arctic side of the divide and that further investigations by the prospectors were contemplated. The area Schrader referred to must have been partly in the Philip Smith Mountains quadrangle, but no other mention of early exploration or mineral discovery within the quadrangle has been found in the literature.

More recently, because of the advent of better maps, better airborne capabilities, and more sophisticated exploration methods, the region has been explored and several mineralized areas have been located. Seventy-five claims, staked since 1971, were still active in 1978. The claims are grouped around four localities. The first locality consists of 2 groups of 28 claims, called the Beaucoup and the Occasional, which were staked by Placid Oil Company in 1971 on occurrences of copper minerals in the southeastern part of the quadrangle between the Middle Fork of the Chandalar and Wind Rivers. Interest in the second locality began with the delineation of an anomalous zinc-lead area by the AMRAP investigation (Detra, 1977). Investigations by Noranda Exploration Incorporated and Resource Associates of Alaska resulted in the staking of 47 claims in 2 groups on zinc, lead, and copper minerals in an area between the Middle Fork of the Chandalar River and Your Creek. Just outside the quadrangle, two small groups of claims, about 6, have been located on occurrences of copper and silver minerals. One group is 7 km south and the other is 7 km northeast of the southeast corner of the quadrangle. Other exploration targets suggested by the AMRAP study include strata-bound and vein deposits. The presence of porphyry and contact metamorphic mineralization to the south (DeYoung, 1978) may also influence mineral exploration in the Philip Smith Mountains quadrangle.

No economic deposits of oil, gas, or coal are known although the geologic regime of the northwestern part of the quadrangle is compatible with the presence of these hydrocarbons.

Eleven wildcat wells have been drilled in similar rocks in the adjoining Sagavanirktok quadrangle to the north. Ten of these are dry holes, including the nearest two wells, which are 12 km and 17 km north of the quadrangle boundary (Tailleur, Pessel, and others, 1978). The only success was a gas well located 45 km north of the quadrangle. Geophysical exploration related to these wells probably extended into the quadrangle, but the record has not been made public.

To date the only minerals produced from within the Philip Smith Mountains quadrangle have been rock, gravel, sand, and fill. All material quarried was used locally in the construction of roads, airstrips, and building sites for the Trans-Alaskan pipeline. The volume of quarried material as of March 1977 was approximately 7.6 million cubic meters (Al Alson, written commun., 1977).

GEOLOGICAL INVESTIGATIONS

PREVIOUS INVESTIGATIONS

The Philip Smith Mountains quadrangle was virtually unmapped until military aerial photography of northern Alaska was obtained during World War II. In the 1936 edition of the Geological Survey map of Alaska (Map E), the area of the quadrangle north of the Chandalar River system is blank; no northward-flowing streams are shown. The first reconnaissance topographic map was published in 1951.

Only the extreme southwestern part of the quadrangle was explored by early-day geologists and topographers. In 1899, during their reconnaissance of the Chandalar and Koyukuk Rivers, F. C. Schrader, geologist, and T. G. Gerdine, topographer, mapped northward along the present highway route in the Dietrich Valley but did not get far enough to recognize Atigun Pass (Schrader, 1900, 1904). In 1923, J. B. Mertie, Jr. mapped the geology of the Chandalar quadrangle and extended his foot-traverse mapping about 10 km northward into the Philip Smith Mountains quadrangle in the area between the highway and Your Creek (Mertie, 1925). In 1927, Mertie continued his mapping northeastward, and although his route was 25-100 km east of the Philip Smith Mountains quadrangle, he traversed across the strike of most of the Paleozoic rocks found in the quadrangle (Mertie, 1929).

In 1934, Robert Marshall published a geographic sketch map of the northern Koyukuk region based on his own compass surveys and on information from prospectors and trappers. His map (Marshall, 1934), which included a small part of the quadrangle west of the North Fork of the Chandalar River, improved on the earlier maps by recognizing a pass across the continental divide from the highway route westward into the Itkillik Valley although it did not show the pass into the Atigun Valley. North of the divide, the quadrangle remained unmapped.

Although only a small part of the quadrangle was visited during these early investigations, the geologic work by Mertie in the adjacent quadrangles in 1923 and 1927 enabled him to describe a stratigraphic succession of the major rock units of Silurian, Devonian, and Mississippian age that also describes most of the rocks within the Brooks Range in the Philip Smith Mountains quadrangle.

RECENT INVESTIGATIONS

Fieldwork used in the present report began in 1949, when detailed stratigraphic studies of the Lisburne Group carbonate rocks and some limited geologic mapping were done at Itkillik Lake (Bowsher and Dutro, 1949). This work and an earlier geologic reconnaissance boat traverse down the Atigun and Sagavanirktok Rivers (Gryc and Lathram, 1946) were part of the geologic studies related to the determination of the petroleum potential of Naval Petroleum Reserve No. 4. From 1950 through 1952, and again in 1965, additional fieldwork pertaining to that program included areas of study within the quadrangle. Geologic mapping in 1950 along the north front of the Brooks Range included the northwest edge of the quadrangle along the Itkillik River (Patton and Tailleur, 1964). That same year, stratigraphic studies and some limited mapping were done at Galbraith Lake (Brosgé and Reiser, 1951; Brosgé and others, 1962). In 1951 geologic mapping to the east along the front of the Brooks Range included most of the foothills east of the Sagavanirktok River (Keller and others, 1961). In the following years, a number of short traverses were made in the quadrangle primarily for stratigraphic studies. These were at: Elusive Lake in 1952 and Your Creek in 1958 (Brosgé and others, 1960), Atigun Gorge by Tailleur in 1965 (Imlay, 1967), and the Ivishak and Saviukviayak Rivers in the northeast part of the quadrangle in 1969 and 1972

(Detterman, 1976). The authors made short helicopter traverses south of the Continental Divide in 1960 and along the Dietrich River and the head of the Sagavanirktok River in 1974. During 1976 and 1977, the U.S. Bureau of Mines made field reconnaissance studies in the eastern Brooks Range which included the eastern part of the Philip Smith Mountains quadrangle (Barker, 1978). The results of these investigations provided background and supplemental data which have been used in preparing this circular and the folio.

Planning and construction of the Trans-Alaskan pipeline (1969-77) initiated a number of special geologic and hydrologic studies concerned with the pipeline and its right-of-way. The areas within the Philip Smith Mountains quadrangle are discussed in many of the reports. For information regarding these studies, the reader is referred to the comprehensive bibliographies of the quadrangle compiled by E. H. Cobb of the U.S. Geological Survey (Cobb, 1974-79). Field studies of surficial geology by T. D. Hamilton were begun along the pipeline route in 1969 and continued until 1971.

Reconnaissance gravity data were collected by the Geological Survey in this part of the Brooks Range in the early 1960's. More detailed gravity data in the quadrangle were obtained during the pipeline leveling (W. E. Strange, National Oceanic and Atmospheric Administration, written commun., Sept. 1976) and in conjunction with the 1976 geochemical sampling. All available data have been incorporated in a simple Bouguer anomaly map (Barnes, 1977), and a terrain corrected map is forthcoming pending the availability of digital elevation data.

Regional geologic bedrock mapping for AMRAP began in the Philip Smith Mountains quadrangle in June 1975 and continued into August 1975. In the 1976 field season, an extensive geochemical reconnaissance sampling program was carried out during June and July under the direction of S. P. Marsh and J. B. Cathrall, and the bedrock mapping program was completed in August. During these same field seasons, T. D. Hamilton independently mapped the quadrangle's surficial deposits. In order to complete this fieldwork, the geologists relied heavily upon helicopter support. The aeromagnetic survey was flown in 1976 and interpreted by J. W. Cady in 1977. Landsat imagery was acquired in 1974 and interpreted by J. R. Le Compte in 1978.

GEOLOGIC SUMMARY

STRATIGRAPHY

Almost all the rocks exposed in the Philip Smith Mountains quadrangle are sedimentary. They form a Silurian to Cretaceous stratigraphic sequence about 8 km thick; the sequence is interrupted by several erosional unconformities but has no major angular unconformities (see figs. 3 and 4). Successively older parts of this sequence are exposed from north to south across the quadrangle (fig. 5). Jurassic and Cretaceous rocks form the Arctic Foothills. Mississippian to Triassic rocks form most of the Brooks Range north of the Continental Divide; the Kanayut Conglomerate, the youngest of the Devonian formations, crops out along and immediately north of the divide, and the Silurian and older Devonian formations form most of the mountains south of the divide.

The stratigraphic sequence contains two lithologic cycles; each cycle is about 4 km thick and each cycle culminates in the coarse clastic deposits of a major orogeny. The lower cycle consists of the Silurian and Devonian rocks of the Franklinian sequence (Lerand, 1973); the upper cycle consists of the Mississippian to Cretaceous rocks of the Ellesmerian and Brookian sequences. In each cycle, about 600-800 m of carbonate rocks are succeeded by 1,700-2,000 m of marine shale and siltstone, and these are succeeded by 1,000-1,500 m of marine and nonmarine sandstone and conglomerate. The thick shale that forms the middle of each cycle is mostly dark gray to black. The Jurassic and Cretaceous shales in the upper cycle are rich enough in organic material to be regarded as the probable source rocks for the oil in the Prudhoe Bay field (Morgridge and Smith, 1972). The shales and the thick carbonate units that underlie them in each cycle are also important to the mineral resource assessment as potential host rocks for strata-bound metal deposits. In both cycles the coarse-grained rocks above the shale are mostly cyclically bedded fluvial deposits with a basal marine sandstone. An additional thick sequence of coarse-grained rocks comprises the southernmost outcrops of the Cretaceous section where, instead of the Cretaceous black shale

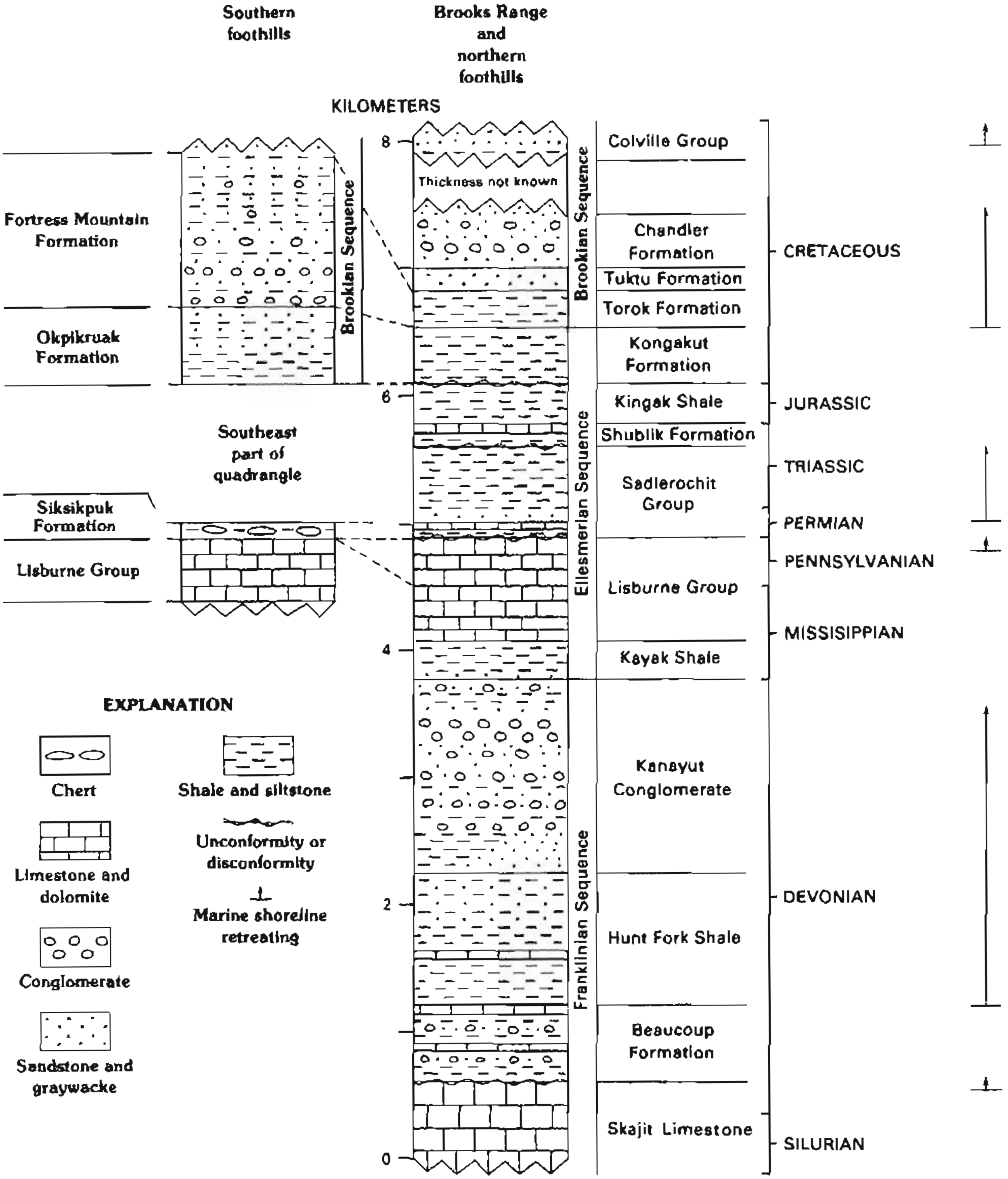

FIGURE 3.—Generalized stratigraphic sections of Paleozoic and Mesozoic rocks exposed in Philip Smith Mountains quadrangle. Stratigraphic sections show name, age, dominant rock types, and approximate thickness of each formation or group.

that occurs farther north, there is a thick unit of graywacke turbidite overlain by a very coarse graywacke conglomerate that contains some clasts of igneous rocks (see fig. 3).

Lerand (1973) divided the rocks along the Beaufort Sea into the Franklinian and Ellesmerian sequences, whose rocks were derived mainly from old land areas to the north, and the Brookian sequence, whose rocks in Alaska were derived from a new land area that rose in the south during the Mesozoic to form the ancestral Brooks Range. The rocks exposed in the Philip Smith Mountains quadrangle are the deposits of a series of marine transgressions and retreats around these land areas; the major retreats occurred during the compressional Ellesmerian and Laramide orogenies and several minor retreats may be related in part to periods of extensional block-faulting and vertical uplift (Hitzman, 1980).

The Skajit Limestone was deposited in a shallow sea on a stable shelf. Subsequent local uplifts at the beginning of the Late Devonian resulted in some erosion and silicification of weathered surfaces before the overlying Devonian shale and conglomerate of the Beaucoup Formation was deposited in deepening water. Where the sea remained shallow, small carbonate reefs interfingered in the Beaucoup shales.

The thick Upper Devonian clastic wedge composed of the marine Hunt Fork Shale and the

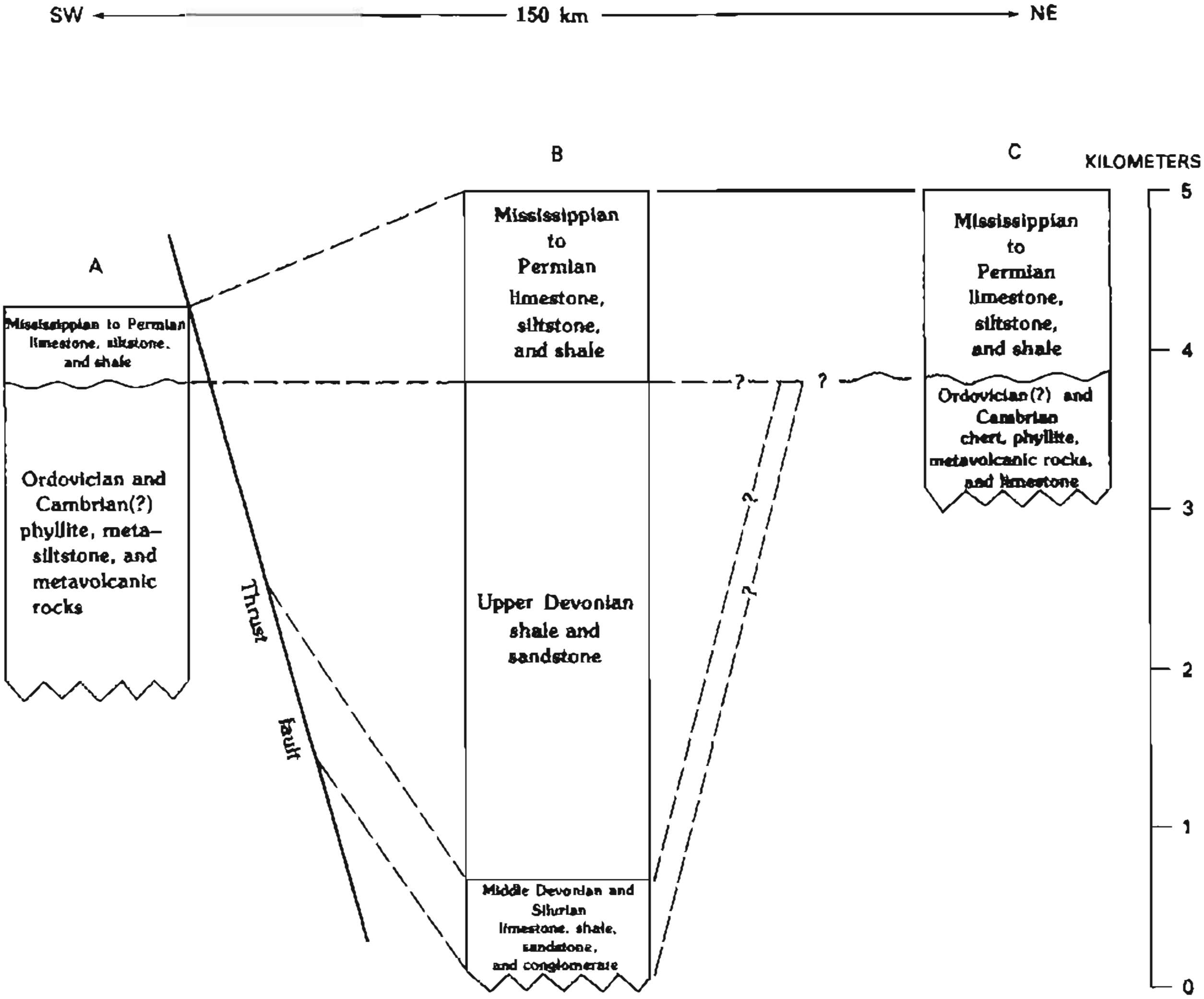

FIGURE 4.—Generalized stratigraphic columns showing the Paleozoic sequences exposed in the central and southern Philip Smith Mountains quadrangle (B) and on the Doonerak Anticline 8 km southwest of the quadrangle (A); and the inferred Paleozoic sequence in the northeastern part of the quadrangle (C), where rocks older than Mississippian are not exposed.

overlying largely nonmarine Kanayut Conglomerate marks a major retreat of the shoreline that was caused by the outpouring of these deltaic deposits away from a land area to the northeast during the Ellesmerian orogeny. The shoreline gradually transgressed northward again during the deposition of the Mississippian Kayak Shale and the overlying carbonate rocks of the Mississippian and Pennysivanian Lisburne Group. The direction of transgression is demonstrated by the fact that each of these marine formations is slightly younger to the north. The Lisburne carbonate deposits evidently filled up the basin, so that no Upper Pennsylvanian strata were deposited, and the upper surface of the Lisburne was exposed locally to erosion, marking a minor

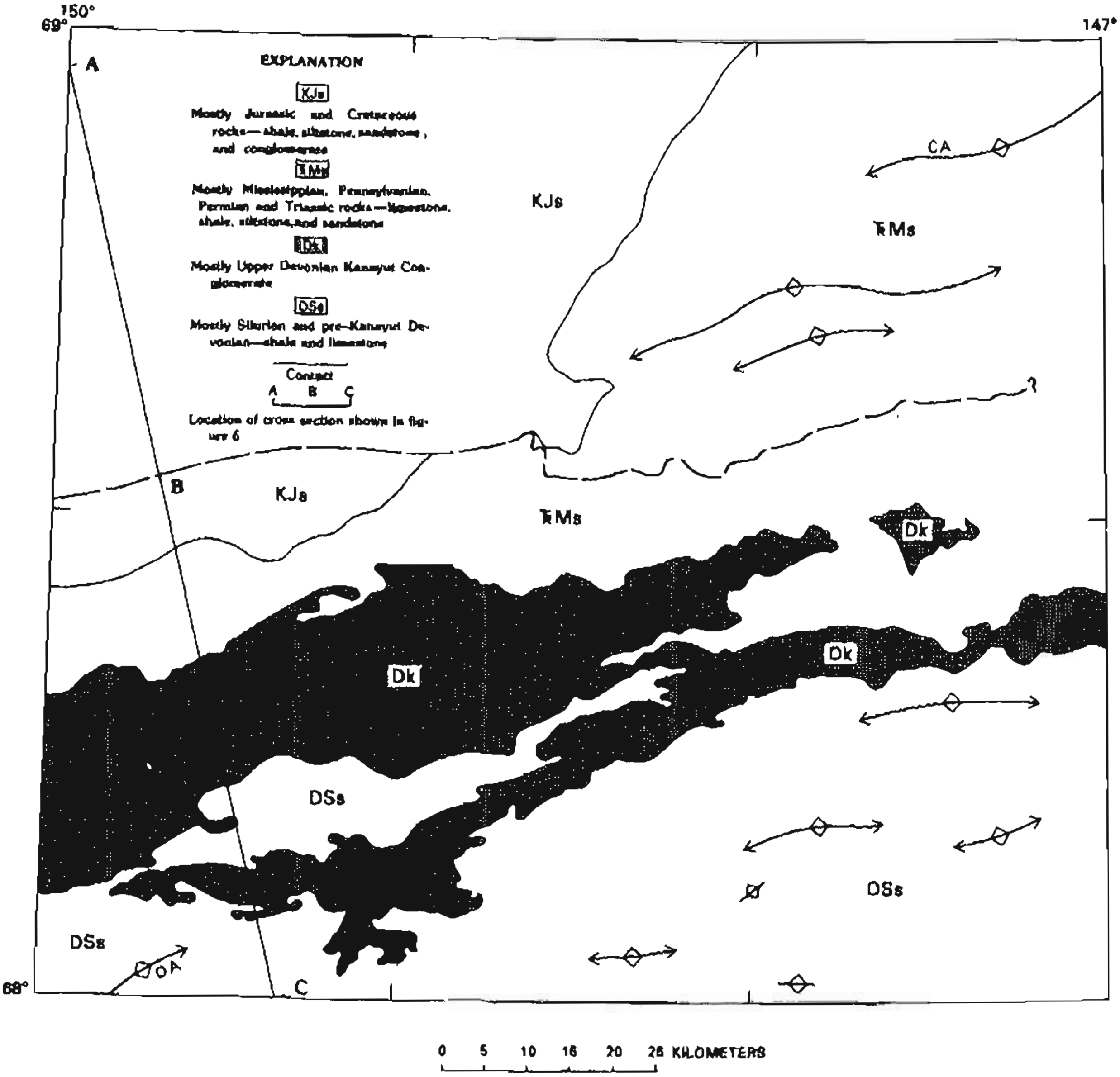

FIGURE 5.—Generalized geologic map of the Philip Smith Mountains quadrangle. Barbed heavy lines show location of axes of anticlines mentioned in the text; arrows show direction of plunge. DA is Doonerak anticline; CA is the anticline in which Cambrian rocks are exposed farther east. Dashed line is inferred location of the north edge of the thrust plate that contains most of the exposed Kanayut Conglomerate, and it is also the approximate northern limit of the area in which large thrust faults are common in the Paleozoic rocks.

regression of the shoreline. Above the Lisburne, the Permian shallow marine sandy and limey rocks at the base of the Sadlerochit Group also become younger northward. The Permian rocks thus represent a second northward transgression of the marine shoreline across a northern land area. At the same time, the Permian chert and shale of the Siksikpuk Formation were being deposited in deeper water to the south. In contrast, the Triassic shale and siltstone in the upper part of the Sadlerochit Group are the southern marine facies of a delta system that becomes coarser and partly nonmarine north of the quadrangle. The Triassic rocks thus represent another retreat of the shoreline caused by deltas growing southward from a northern land area.

Above the Sadlerochit Group the deepwater limestone and shale of the Triassic Shublik Formation and the black marine shales of the Jurassic Kingak Shale and Lower Cretaceous Kongakut Formation show that the sea again transgressed the northern land. But, at the same time, the ancestral Brooks Range was rising to the south at the beginning of the Laramide orogeny. While the Cretaceous marine black shales of the Kongakut and Torok Formations were being deposited in the northern part of the Arctic Foothills, the marine turbidites of the Okpikruak Formation and the partly nonmarine conglomerate of the Fortress Mountain Formation were being deposited near the mountains that were rising to the south. The Torok Formation itself is the shaly offshore marine facies of an Early Cretaceous delta system that gradually advanced northward and eastward into the area so that eventually the marine sandstone of the Tuktu Formation and the partly nonmarine conglomerate of the Chandler Formation were deposited above the Torok.

In well exposed outcrops west of the quadrangle, the Upper Cretaceous Colville Group represents a final marine transgression and then another northward retreat of the shoreline, during which marine and nonmarine deltaic deposits again prograded northward from the Brooks Range. These rocks may be 1,000 m thick in the northern part of the quadrangle, but they have not been measured because only a few beds of sandstone, coaly shale, and tuff are exposed beneath the extensive cover of glacial deposits. Since Tertiary time the shoreline has remained to the north.

The only igneous rocks exposed in the quadrangle are small basaltic flows and sills in the Devonian shale in the southeast part of the area, a few thin mafic dikes in the Skajit Limestone, and a diorite sill in the Lisburne Group at the northeast edge of the quadrangle. The diorite is probably contemporaneous with small andesitic flows that occur in the Lisburne 10 km farther north. A small granitic pluton at a depth of 1.2-2.5 km may be inferred from a magnetic anomaly in the area of Mississippian rocks in the northeast (Cady, 1978), but the nearest known outcrops of granitic rocks are 15 km south of the quadrangle.

A wide belt of greenschist and higher grade metamorphic rocks surrounds the granitic rocks that crop out south of the quadrangle, and the zone of low-grade greenschist metamorphism extends into the southern part of the quadrangle. In that area, the Devonian shale is commonly metamorphosed to slate and locally to phyllite, and many of the Devonian basalts have been altered to greenstone. Devonian and younger rocks farther north are unmetamorphosed.

STRUCTURE

Most of the rocks in the Brooks Range and in the southern part of the Arctic Foothills are tightly folded and thrust faulted on both a large and a small scale (fig. 6). The deformation was caused by the Laramide orogeny that probably began in the Jurassic or earliest Cretaceous and continued into the Tertiary. The intensity of this deformation decreases in the northern quarter of the quadrangle. The younger Cretaceous rocks in the northwest are exposed in broad, gently-folded synclines, and the Mississippian to Triassic rocks in the northeast, although compressed into tight west-plunging folds, seem not to be broken by many thrust faults. The northern limit of the area in which large thrust faults are abundant is shown on figure 5.

The dip of axial planes of folds ranges from vertical to about 30° and is generally to the south. However, the axial planes dip northward in the two large anticlines in Mississippian rocks that are shown on figure 5 just north of the northern limit of large thrust faults. This local dip reversal may reflect an arch in the basement rocks.

Imbricate thrust faults are the most striking style of deformation in the Kanayut Conglomerate and in a 15-20-km-wide zone of younger rocks immediately north of the outcrops of the Kanayut. Most of these faults seem to be at the leading edges of broken overturned anticlines, and generally the displacement on each fault diminishes along strike so that the structure ends as an unbroken plunging anticline. However, bedding-plane thrusts with displacements of at least 4-8 km do occur in the Mississippian rocks, particularly at the front of the range in the western part of the area (see fig. 6) and directly north of the large thrusts and folds in the Kanayut Conglomerate in the eastern part of the area. Bedding plane thrusts also probably occur at depth in the Mesozoic shales of the Arctic Foothills and throughout the Paleozoic rocks of the Brooks Range.

The most complex folds are in the Devonian shale in a zone just south of the Kanayut Conglomerate belt. In that area, marker beds of the Kanayut Conglomerate, and locally of the Skajit Limestone, have been infolded in the shale, and these beds outline recumbent isoclinal folds with amplitudes of about 6 km and with gently dipping to horizontal axial planes (see south end of fig. 6). Southeast of this zone the shale may be highly deformed, but the underlying Skajit is exposed in a series of fairly symmetrical doubly-plunging anticlines and small domes whose axes are shown on figure 5.

SUBSURFACE BASEMENT ROCKS

The sequence of rocks hidden beneath the Mississippian to Triassic rocks in the northeastern part of the quadrangle (fig. 4) is probably very different from the sequence of Silurian and Devonian rocks that is exposed to the south (fig. 3). In exposures of pre-Mississippian rocks north and east of the quadrangle and throughout the northeastern Brooks Range, the Devonian shale and conglomerate formations are absent and the Mississippian rocks rest with angular unconformity on deformed rocks of Precambrian, Cambrian, and probable Ordovician age. The southernmost-known exposure in which these deformed basement rocks lie directly beneath the Mississippian is about 40 km east of the quadrangle on a west-plunging anticline whose axis (CA on fig. 5) extends into the northeastern corner of the quadrangle. It is likely that the Cambrian and Ordovician(?) chert and volcanic rocks exposed to the east on this anticline continue beneath the Mississippian for some distance westward into the northern Philip Smith Mountains quadrangle. Similarly, the Mississippian in wells 150 km north of the quadrangle at Prudhoe Bay rests unconformably on deformed Ordovician(?) and Silurian argillite (Carter and Laufeld, 1975). This unconformity continues southward in the subsurface beneath the cover of Mesozoic rocks

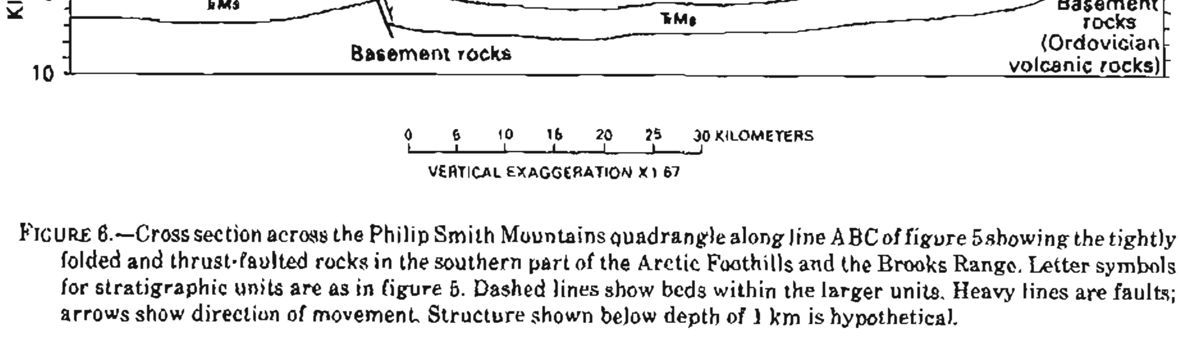

FIGURE 6.—Cross section across the Philip Smith Mountains quadrangle along line ABC of figure 5 showing the tightly folded and thrust-faulted rocks in the southern part of the Arctic Foothills and the Brooks Range. Letter symbols for stratigraphic units are as in figure 5. Dashed lines show beds within the larger units. Heavy lines are faults; arrows show direction of movement. Structure shown below depth of 1 km is hypothetical.

(Tailleur, Bird, and Engwicht, 1978) and may extend into the Arctic Foothills within the quadrangle. Thus both in the Arctic Foothills and in the Brooks Range the southern limit of the area in which the Mississippian may rest on pre-Devonian basement rocks is probably within the quadrangle.

The northern limit of the area in which the Devonian Hunt Fork Shale and Kanayut Conglomerate are actually present beneath the Mississippian is also not exactly known. The Devonian rocks that are actually exposed in the quadrangle, together with the Mississippian to Triassic rocks that immediately overlie them, seem to have glided 20-30 km northward on a flat thrust plate in the Devonian shale (fig. 6). The approximate northern limit of this thrust plate, shown on figure 5, is terminated with a question mark near the east side of the quadrangle where the displacement on this and adjacent thrusts seems to die out. The northern terrane that lacks Devonian rocks may extend some distance southward beneath this thrust plate.

It is possible that the northern basement terrane may extend beneath the entire quadrangle at depth, because the same kind of terrane is exposed again just south of the quadrangle on the Doonerak anticline (DA on fig. 5) which plunges northeastward into the southwest corner of the quadrangle. In the core of this anticline, Mississippian rocks rest unconformably on Ordovician volcanic rocks and phyllite (Dutro and others, 1976) and are overlain by a thrust plate composed of Devonian shale that is continuous with the Devonian shale within the quadrangle. The lower part of the cross section in figure 6 was drawn to illustrate the hypothesis that all the Devonian rocks in the Philip Smith Mountains quadrangle are parts of this thrust plate and were moved into the quadrangle from an original position south of the Doonerak anticline—a displacement of at least 50 km. The Ordovician or older basement rocks inferred for the northern part of the quadrangle and the Mississippian and younger rocks that overlie them may extend beneath this thrust plate to where they are exposed again on the Doonerak anticline. This hypothesis would explain all the observed relations except that no fault of such large displacement has been recognized in the Mississippian to Triassic rocks in the mountainous eastern part of the quadrangle where the leading edge of the thrust plate should be exposed.

DESCRIPTION OF COMPONENT MAPS

SURFICIAL GEOLOGY
(MAP MF-879A)

The initial fieldwork along the Atigun and Sagavanirktok valleys was carried out in connection with trans-Alaska pipeline activities in 1969-71, and the entire Philip Smith Mountains quadrangle subsequently was covered by ground and helicopter traverses during 1975 and 1976. Able assistance during the 1975 and 1976 field seasons was provided by Robert M. Thorson.

The surficial geologic map of the Philip Smith Mountains quadrangle is based on (1) surface observations of morphology and composition of unconsolidated deposits, (2) examination of test pits, trenches, road cuts, and other shallow excavations, (3) stratigraphic study of bluff exposures, and (4) analysis of maps and drill logs prepared by U.S. Geological Survey personnel and Alyeska consultants for the trans-Alaskan pipeline corridor (see Map MF-879B). Placement of glacial deposits within the standard central Brooks Range stratigraphic sequence (Detterman and others, 1958; Williams, 1962; Hamilton and Porter, 1975) was based on (1) similarities in position, extent, and postglacial modification to the Anaktuvuk, Sagavanirktok, Itkillik, and Echooka drift sheets at type localities designated by R. L. Detterman and (2) concordant or crosscutting relationships of drift sheets, valley trains, and meltwater channels in neighboring valleys. Drift nomenclature has been revised in accordance with the recommendations of Keroher and others (1966) and Hamilton and Porter (1975). The originally published names Anaktuvuk and Sagavanirktok Glaciations have been changed to the "Anaktuvuk River Glaciation" and "Sagavanirktok River Glaciation" to avoid conflict with previously named rock units (Keroher and others, 1966, p. 91 and 3379; Sable, 1977, p. 24-30). The names Itkillik Glaciation and Echooka or Echooka River Glaciation are replaced by "Itkillik I," "Itkillik II," and "late Itkillik"; these names correspond to the glacial sequences described and illustrated by Hamilton and Porter (1975).

Surficial geology of the Philip Smith Mountains quadrangle is dominated by the effects of successive episodes of Pleistocene valley-glacier activity. The glaciers deeply scoured mountain passes and valleys systems and deposited vast quantities of till, ice-contact stratified drift, and outwash at and beyond the margins of the Brooks Range. They also eroded the lower slopes of the valley walls and created oversteepened, unstable rock faces that are subject to falls and slides of rock and debris which accumulate as talus and landslide rubble. Glacial retreat from massive end moraines near the north flank of the range left closed and partly closed basins (stippled pattern) which received thick deposits of lacustrine sediment, alluvium, fluvial and eolian sand, and fan-delta sediments at the mouths of tributary streams. The older glacial deposits generally are more weathered, more dissected by stream erosion than the younger deposits, and the older deposits often bear relatively thick blankets of ice-rich frozen silt and muck. The younger deposits are less altered by postglacial processes, hence they provide more suitable and readily accessible construction materials.

Massive overlapping drift sheets were deposited beyond the north flank of the range during each Pleistocene glaciation. The oldest drift, of Anaktuvuk River age, was formed by coalescing piedmont glaciers that spread relatively freely over the low terrain north of the range front. Younger glacial deposits, of Sagavanirktok River age, formed massive lateral moraines 200-300 m high that confined the outermost drift of the succeeding Itkillik glaciers. Thick and extensive loess, colluvium, and thaw-lake sediments cover the older drift and outwash deposits; in contrast, blankets of ice-rich organic silt tend to be thin and commonly are absent above drift and outwash deposits of Itkillik age. Itkillik II deposits, characterized by extensive ice-contact and outwash gravel, provide particularly well drained and stable surfaces for transportation routes, structures, and borrow materials. Late Itkillik deposits locally provide favorable surfaces, but elsewhere the drift consists mainly of poorly sorted till and fine-grained glaciolacustrine sediment.

Holocene glacier and rock-glacier activity has been restricted to relatively high altitudes, predominantly in a 25-km-wide belt centered on the Continental Divide. Older drift of presumed Neoglacial age forms bouldery vegetated moraines that terminate at altitudes of 900-1200 m 3-8 km from cirque headwalls. Younger Neoglacial drift forms fresh unstable moraines that typically occupy cirque floors close to the fronts of existing glaciers. Rock glaciers are active along valley sides at altitudes above about 1,000 m and occupy cirque floors and headwalls at higher altitudes. Most rock glaciers were formed from talus, but many rock glaciers within cirques have developed from glacial debris. Additional Holocene deposits include beaches along lake shores, solifluction sheets and aprons on slopes, earthflows where unstable banks of till have been exposed by river downcutting, alluvium along valley centers, and fans at the mouths of tributary streams. Many of these deposits are much more abundant than indicated on the map because the scale is too small to show alluvium along smaller tributary valleys, minor earthflows on moraine surfaces, and small or thin sheets of talus and solifluction debris.

With the exception of alluvium beneath some of the largest rivers and lakes, all surficial deposits of the Philip Smith Mountains quadrangle are perennially frozen. Permafrost lies at shallow depths (0.1-0.6 m) beneath most surfaces north of the Brooks Range; its depth is more variable (0.2-2 m) within mountain valleys north of the Continental Divide. South of the Divide, unfrozen alluvium is more widespread than it is north of the divide, and permafrost tends to occur at greater depths (0.3-3 m).

Radiocarbon dates from the central Brooks Range indicate that the Itkillik I glacial phase occurred more than 53,000 radiocarbon years ago and that glacier advances during the Itkillik II phase attained maxima between about 24,000 to 16,000 yr B.P. (Hamilton, 1982). Late Itkillik readvances took place about 13,000-12,500 yr B.P., and post-Itkillik basin filling commenced by at least 10,500 yr B.P. in some valleys (Hamilton, 1979a, b). Middle and late Holocene cycles of alluviation and downcutting have been dated in the Itkillik, Atigun, Ribdon, and Sagavanirktok valleys. At least two of these cycles, which took place about 3,800-2,000 yr B.P. and within the past 500 years, evidently were caused by accelerated glacial and periglacial sedimentation related to expansion of cirque glaciers at valley heads (Hamilton and others, 1982).

BEDROCK GEOLOGY

(MAP MF-879B)

The bedrock geology of the Philip Smith Mountains quadrangle is shown in black and white at 1:250,000 scale on map MF-879B. On this map, the area shown as bedrock has been expanded at the expense of the area shown as surficial deposits wherever the deposits are thin and the character of the bedrock can be inferred readily. A generalized version of this map is used as the base for the other component maps of the folio. In both of these published geologic maps, the Upper Devonian rocks beneath the Hunt Fork Shale have been described as members of an unnamed unit of "brown calcareous clastic rocks." Since these maps were published, the name Beaucoup Formation (Dutro and others, 1979) has been established to include most of these unnamed rocks.

Detailed descriptions of some of the stratigraphic units have been given in separate reports. The Sadlerochit Group was described by Detterman (1976); the Lisburne Group by Bowsher and Dutro (1949), Brosgé and others (1962), Armstrong and others (1970), and Armstrong and Mamet (1977, 1978); the Hunt Fork Shale by Dutro (1978); and the Beaucoup Formation by Dutro and others (1979).

MINERAL RESOURCES OTHER THAN OIL AND GAS (MAP MF-879C)

The quadrangle's mineral deposits and occurrences and its potential mineral resources other than oil and gas are described in MF-879C. Locations of the known deposits are shown on the map, and the deposits are classified by type and chief commodity in an accompanying table. Mineral production from the quadrangle has consisted solely of sand, gravel, rock, and fill that was used locally, primarily for construction of the Alyeska pipeline.

Only in the last 10 years has there been active interest in the metalbearing deposits of the Philip Smith Mountains quadrangle. The interest is reflected in several groups of claims on the lead, zinc, and copper deposits shown on the map (Menzie and others, 1982). The known deposits and occurrences have not been drilled, and exploration in the quadrangle has been scant.

Although few metal-bearing deposits are known, the information presented in the folio of maps that accompany this report suggests that a number of vein-type and strata-bound deposits in shale and in carbonate rocks may occur in the quadrangle. The scarcity of intrusive rocks (which was interpreted from the aeromagnetic map) was used to eliminate from consideration those types of deposits that are closely associated with igneous rocks.

Ideally a resource assessment should consist of three basic steps (Singer, 1975):

1. Delineation of areas that are geologically permissive for various types of mineral deposits.
2. Estimation of the number of deposits of each type within each delineated tract.
3. Construction of grade-tonnage or contained metal models for the deposit types.

In this quadrangle, this ideal methodology had to be modified. Deposits that may exist within the Philip Smith Mountains quadrangle are likely to be of stratiform or strata-bound types. For these deposit types, only a limited amount of both geologic and grade/tonnage information is available for model building. Thus it was only possible to construct one preliminary grade/tonnage model for use in the resource assessment. Because only a limited amount of exploration has been undertaken in the quadrangle and because an estimate of number of deposits has little meaning without an associated grade/tonnage model, no attempt was made to estimate numbers of deposits. However, tracts of land that potentially contain deposits of different types were delineated. The possibility exists that tracts designated as permissive may not contain deposits, and also that areas not commented upon may contain deposits.

Boundaries of the mineral resource areas were determined by the authors of the component maps of this study, assisted by J. T. Dutro, Jr., and J. A. Briskey, Jr. Final responsibility rests with the authors of the mineral resources map. The tracts were outlined on the basis of their known deposits and their potential for undiscovered deposits as interpreted from geologic, geophysical, and geochemical data presented in other maps of the folio. The types of deposits that may occur in these tracts were inferred from occurrences in similar geologic settings elsewhere. The particular criteria used to delineate each tract are listed on the map sheet. Tract boundaries were not allowed to extend beyond geologic units that are permissive for the occurrence of a deposit type. Tracts were also restricted in areal extent if examination demonstrated absence of mineralization.

Of the metal-bearing deposit types delineated, only vein deposits containing copper, lead, and(or) zinc are known to occur in the quadrangle. Although locally vein deposits can be rich, they are typically low in tonnage. Lead and zinc-bearing strata-bound deposits of the shale-hosted type or the carbonate-hosted Mississippi Valley type have not been observed, but they are known to occur elsewhere in geologic environments that are similar to the delineated tracts in the Philip Smith Mountains quadrangle. If strata-bound deposits are in the quadrangle, then their tonnages may be large; in northwestern Canada and in northwestern Alaska, deposits of this type have been discovered that have tonnages ranging from 10's to 100's of millions of tons. Mississippi Valley type deposits, not previously discovered in Alaska, probably have tonnages that are slightly lower than strata-bound shale-hosted deposits.

OIL AND GAS RESOURCES

(MAP MF-879D)

The potential for hydrocarbon accumulations in the Philip Smith Mountains quadrangle is estimated, with a large degree of uncertainty, to be low to moderate for the northwest third of the area, and low for the remaining area. The uncertainty stems primarily from the absence of subsurface data which are necessary in understanding the relation of surface geology to subsurface geology—a relation most difficult to determine in this area because of thrust faulting.

The quadrangle is located on the southeast edge of the North Slope petroleum basin. It is situated 140 km south of the Prudhoe Bay oil field, 48 km south of the nearest hydrocarbon accumulation, the Kemik gas field, and 10 km from the nearest exploratory well (fig. 7). The quadrangle also straddles the western North American Thrust Belt province. This province is a folded and thrust-faulted belt of sedimentary rocks about 150 km wide, and it extends continuously from northern Alaska through Canada to at least as far south as Arizona. There is considerable current exploratory interest in this province because of numerous significant petroleum discoveries, originally in Canada and, most recently, in Wyoming and Utah (Lamb, 1980; Powers, 1980).

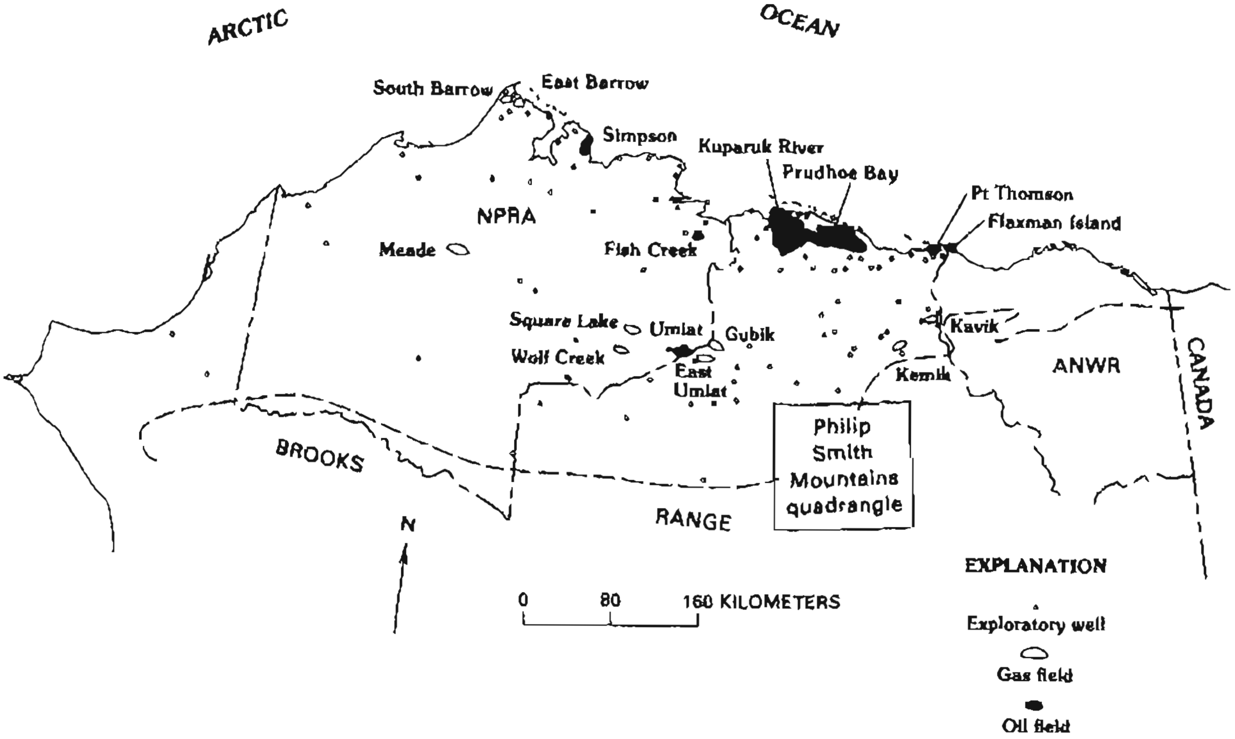

FIGURE 7.—North Slope petroleum basin (mostly north of Brooks Range) showing locations of hydrocarbon accumulations, exploratory wells, and Philip Smith Mountains quadrangle.

Although petroleum reservoir potential in the quadrangle is judged low to moderate, relevant data are sparse. Cretaceous sandstones are mostly graywackes, and these sandstones in nearby wells exhibit fair porosity (up to 15 percent) in the youngest strata and poor porosity (less than 10 percent) in the older strata. Pre-Cretaceous sandstone, primarily that in the Kanayut Conglomerate, is described as quartzite, and the porosity in the Cretaceous sandstone is expected to be less than 10 percent. Carbonate reservoirs with greater than 5 percent porosity are present in the dolomites of the Lisburne Group (Brosgé and Reiser, 1951). However, the occurrence of dolomite in the Lisburne is erratic and presently unpredictable. Dolomite of unknown porosity is present in the Skajit Limestone.

The petroleum source rock potential is good, and the rocks are mature as indicated by geochemical analyses of outcrop samples and samples from nearby wells. The best source rocks (>1 percent organic carbon and predominantly amorphous and herbaceous kerogen) are the Kongakut Formation, Kingak Shale, and Shublik Formation. The poorest source rocks (<0.5 percent organic carbon and predominantly humic and inert kerogen) are the Siksikpuk Formation, the Sadlerochit Group, and the Hunt Fork Shale. Though thermal maturity (>0.65 vitrinite reflectance or >2.5 TAI) is achieved at the stratigraphic level of the Torok Formation, a lower level of the oil-generation stage (>1.2 vitrinite reflectance or >3.5 TAI) occurs at the stratigraphic level of the Siksikpuk and the Sadlerochit. Data are insufficient to determine whether maturity was achieved before or after tectonism and trap formation.

The most difficult facet of the petroleum geology of this area to assess is structure (trap occurrence). Folds and faults are abundant, as described in the geologic summary, but, except in the northwest corner of the quadrangle, most folds are breached. The presence of thrust faulting and the absence of subsurface data leave unresolved many important questions such as: (1) what are the subsurface reservoir characteristics; (2) what is the areal extent of the subsurface reservoirs; (3) what is the depth to autochthonous reservoirs; and (4) what is the degree of stack-up of fault-repeated reservoirs. The petroleum potential of this area could be considered greater if, for example, it were known that the Devonian reef deposits, the Hunt Fork Shale, and the Skajit Limestone occurred at drillable depths beneath the northern front of the Brooks Range, or that the generation and migration of hydrocarbons occurred after the structures were formed.

AEROMAGNETIC MAP AND INTERPRETATION
(MAP MF-879E)

The aeromagnetic survey of the Philip Smith Mountains quadrangle was flown in 1976, and the map was originally released as an open-file report by the U.S. Geological Survey in 1977. The map is remarkably featureless, owing to the sparse magnetic crystalline rocks within the thick sedimentary sequence of the northern Brooks Range. Hence, aeromagnetic data are of little use in delineating the configuration of near-surface rock units, and a relation between aeromagnetic features and areas of resource potential has not been established.

The only major aeromagnetic highs are in the northern part of the quadrangle; these highs are caused by deep-seated sources of unknown rock type and regional extent. Several of these magnetic highs are associated with gravity highs. The probable cause of the anomalies is dense, magnetic mafic or ultramafic basement rocks occurring over a large area north and west of, as well as in, the Philip Smith Mountains quadrangle.

INTERPRETATION OF LANDSAT IMAGERY
(MAP MF-879F)

Interpretations of Landsat data were made on (1) a black and white Landsat mosaic (band 7) of the state of Alaska compiled by the U.S. Department of Agriculture, (2) an unpublished black and white Landsat mosaic (band 7) of the state of Alaska constructed by R. G. H. Raynolds, and (3) computer-enhanced black and white and color Landsat imagery processed by the U.S. Geological Survey in Flagstaff, Arizona. Landsat scenes selected for computer-enhancement were 1773-21014 and 1773-21020, both taken September 4, 1974.

The black and white computer-enhanced product used in this report is a horizontal first derivative image. Color computer-enhanced Landsat images include linearly stretched standard false-color, sinusoidally "stretched" false-color, and simulated natural color images. Each of the computer-enhanced products is a mosaicked composite that was derived from the two images noted above. More detailed descriptions of the various computer-enhancement techniques used in these images are given in Albert and Steele (1976a, b) and Condit and Chavez (1978).

As a geologic mapping tool, Landsat imagery is probably most effective for reconnaissance studies, contributing remotely sensed information about geomorphology, structural features, and variations in spectral response of surficial materials. This information can be used to plan and direct geologic mapping and geochemical sampling. However, in the Philip Smith Mountains quadrangle, where reconnaissance geologic mapping and geochemical sampling were completed prior to the Landsat study, the Landsat interpretation, which itself is an abridged version of similar interpretative investigations previously conducted in other areas of Alaska (Albert, 1975; Albert and Steele, 1976a, b; Albert and others, 1978; Steele and Albert, 1978), augmented geological and geophysical observations by identifying: (1) possible extensions of many mapped faults; (2) many lineaments that were undetected previously; (3) many circular features, some of which have diameters of over 200 km; and (4) arcuate features.

A unique result of this investigation has been the identification of an approximately 700-km-long, east-trending (structural?) zone located in the northern Brooks Range. In the western part of the range, the zone coincides with the north-facing range front, approximating the locations of major thrusts in the area (King, 1969; Beikman and Lathram, 1976; Brosgé and others, 1979). In the north-central part, which includes the Philip Smith Mountains quadrangle, the zone bifurcates to form northern and southern segments, coinciding with the approximate location of several major thrusts (King, 1969; Beikman and Lathram, 1976; Brosgé and others, 1979) and coinciding in part with one of the major lineaments. In the eastern part of the northern Brooks Range, these two segments rejoin to form a single zone that may coincide with the northernmost limit of major thrusting in that region (Beikman and Lathram, 1976; Lathram, E. H., oral commun., 1978). This zone is not directly associated with any of the potential mineral tracts mapped in the Philip Smith Mountains quadrangle. Instead, it marks the northern limit of the tracts believed to be permissive for strata-bound deposits of lead, zinc, and copper, and it separates them from the tracts in younger rocks to the north that are believed to be permissive mainly for zinc.

RECONNAISSANCE GEOCHEMISTRY
(MAPS MF-879G-L)

Reconnaissance geochemical investigations were undertaken in the Philip Smith Mountains quadrangle, Alaska in 1975 and 1976 to help evaluate the mineral resource potential by outlining areas considered to have anomalous metal content. During these field seasons, 759 stream-sediment samples, 39 rock samples, and 737 samples of heavy-mineral pan concentrates from stream sediments were collected and analyzed. One other stream sediment sample was collected in 1974.

Six maps showing the distribution and abundance of copper, lead, zinc, silver, barium, molybdenum, arsenic, antimony, bismuth, tin, and cadmium for the various sample media are presented in the folio. These elements were chosen because they are either ore elements or ore-related elements and relevant to a regional mineral resource appraisal of the Philip Smith Mountains quadrangle and because they adequately reflect the economic potential of the area within the limits of this reconnaissance evaluation. Analytical data for elements normally determined, together with statistical summaries and sample locations, are given in the two open-file reports of Cathrall and others (1977a, b).

SAMPLE SELECTION, PREPARATION, AND ANALYSIS

Stream sediments were chosen as the primary sample medium because of the large size of the area that influences each sample. The general lack of knowledge of the nature or even the existence of mineralization, and the short time available for sample collection dictated regional coverage with widely spaced sample sites. The sites were so selected that the material for each sample was derived from a drainage basin of approximately 10 square kilometers. The processes of weathering, mass transport, and fluvial transport in a drainage basin provide a collecting and compositing mechanism such that a small sample of stream sediment is representative of the rock types in the drainage basin.

Two sample media from the stream sediment were chosen in order to afford maximum coverage of the major geochemical components of each drainage basin. They are (1) the medium to fine fraction (−80 mesh (0.18 mm)) of the active sediment in the bedload of the stream, and (2) the heavy minerals incorporated in the bedload of the stream.

The first type of sample provides a typical geochemical cross section of the transported components of the drainage basin. Its chemical composition is controlled predominantly by the major rock types in the drainage basin and, to a lesser extent, by scavenging materials such as amorphous iron-manganese oxides, clays, and organic matter. Geographically small components of the drainage basin, such as a deposit of potentially economic minerals, are usually reflected in this sample medium, but their influence is often small because of dilution from the rest of the area.

The second type of sample is actually a concentrate of a particular phase of the first. It is used to enhance the detection of less abundant heavy components such as ore-related minerals and to mitigate the enhancing effect of organic material, clays, and, in some instances, iron and manganese hydrous oxide. Most of the sediment is usually composed of minerals, such as quartz, feldspar, and clay, that are of low specific gravity and of little or no interest in the search for mineralization. In contrast, elements of importance in the exploration of many mineral deposits are transported as components of minerals of high specific gravity, and these minerals can be concentrated by simple gravity separation. Even soft or fragile ore minerals that break down easily to small grain sizes, such as galena, sphalerite, cerussite, malachite, and cuprite, can be concentrated by this method.

The stream sediments contain at least 90 percent light minerals, so panning with a gold pan raises the relative amounts of heavy minerals by 10 to 100 times. A 5-kilogram sample usually is panned to about 100 grams, which is a concentration ratio of 50 to 1. Further separations in the laboratory reduce this 100 gram sample to 100 milligrams, resulting in a total concentration ratio of 50,000 to 1 (that is, 1 part per billion becomes 50 parts per million—if there are no losses). These concentration procedures raise the relative content of ore- and ore-related elements so that they can be detected by spectrographic analysis. In the laboratory, the heavy-mineral concentrates were split into three fractions on the basis of the magnetic susceptibility of the minerals, as shown in figure 8. The least magnetic sample split was chosen for analysis for the following reasons. Many of the metals that form ores or are associated with ores also occur in common rock-forming silicate minerals (for example, barium and lead in feldspar). Though these minerals are abundant, they do not contain economic amounts of metals. Their metal content makes up the background of the total metal content. Most iron and magnesium silicate minerals are removed when passed through an electromagnetic separator. The magnetic separation, therefore, further reduces the interference from nonore-related minerals. Most of the ore minerals are nonmagnetic and are concentrated in a nonmagnetic fraction that is analyzed. This concentration accentuates the differences in metal content between the samples from drainage basins that contain ore minerals and those that do not.

The rock and stream-sediment samples were collected, prepared, and analyzed as illustrated in figure 8.

USEFULNESS OF HEAVY-MINERAL CONCENTRATES

There is a higher contrast in metal content between samples in the heavy-mineral separates than in the fine to medium fraction of the stream sediments. Thus, the use of heavy-mineral concentrates from stream-sediments for reconnaissance geochemical evaluation of a logistically difficult and large area like the Philip Smith Mountains quadrangle has decided advantages over the use of the fine to medium fraction of the stream sediments. These advantages are: (1) A much lower sample density is sufficient to obtain useful results. (2) The problem of hard-to-evaluate scattered spot anomalies is largely eliminated. (3) Optical mineralogic studies can be made to determine the minerals of possible economic interest and to eliminate spurious anomalies caused by buckshot, barbed wire, etc.; thus the minerals rather than metal percentages can be used as a prospecting guide. (4) Some economic minerals (for example: cassiterite, fluorite, and wolframite) can be detected only by this method. Because these minerals are resistant to physical and chemical weathering, they are transported primarily as mineral grains, not as ions adsorbed on clays or contained in organic matter as are base metals derived from sulfides. (5) The values of some ore-related elements (arsenic, antimony, cadmium, tungsten, molybdenum, bismuth, and thorium) in the fine to medium fraction of the stream sediment are frequently very close to or below the detection limit for spectrographic and chemical analysis. In the heavy mineral concentrates, the concentration of these elements is raised well above the detection limit. Thus the contrast between mineralized and unmineralized areas is increased, and the anomalies are enhanced. (6) The variable effect of organic matter, which may be present in one drainage basin but not in another, is eliminated. (7) The concentrates are independent of the variable diluting effects caused by variations in sediment transport and hydraulic sorting. Heavy-mineral concentrates have delineated several areas as worthy of follow-up studies.

ANOMALOUS AREAS

The anomalous levels shown for the base metals on the geochemistry maps were chosen at

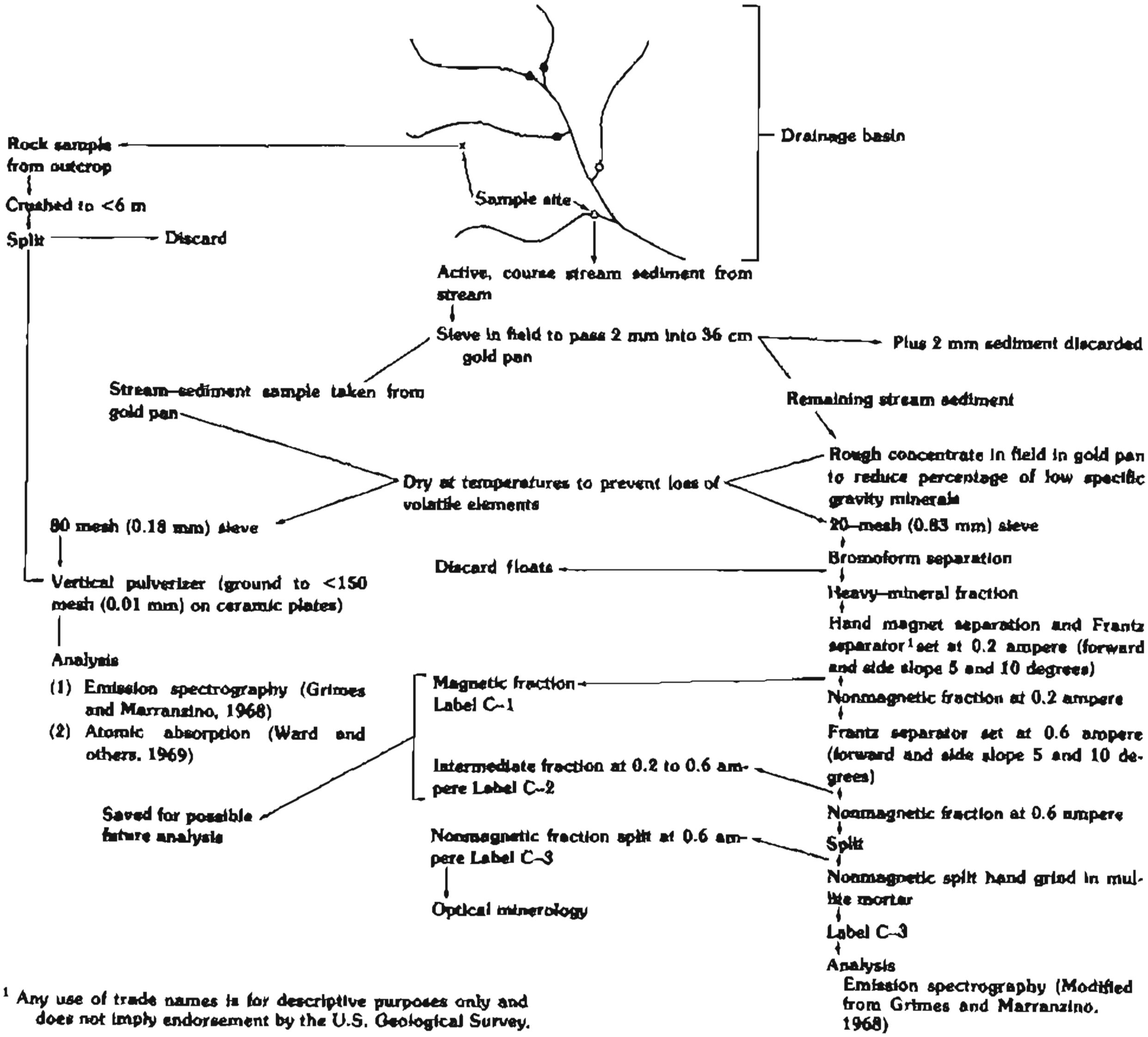

FIGURE 8.—Flow chart showing preparation of rock and stream-sediment samples and of heavy-mineral concentrates from stream sediments, Philip Smith Mountains quadrangle, Alaska.

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[1] Any use of trade names is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey.

the 86th to 96th percentile of the frequency distribution of sample values. In drawing the mineral resource map, the same anomalous levels were used for stream-sediment samples, but higher values, the 93rd to 96th percentile, were used for the heavy concentrates. About 80 percent of these anomalous samples are within the potential mineral tracts that were outlined.

Except in the Atigun Pass area, almost all the copper, lead, and zinc anomalies in the heavy concentrates are south of the Continental Divide where most of the exposed rocks are Devonian. These anomalies are most abundant in the southeastern part of the quadrangle east of Your Creek.

Silver anomalies in the heavy concentrates are also common in these areas, but about half of the silver anomalies are in a separate belt extending through the mountains from east to west across the center of the quadrangle.

Most of the copper, lead, and zinc anomalies in the stream sediments are also south of the divide and east of Your Creek. However, copper and lead are also abundant west of Your Creek, and about one-third of the zinc anomalies are in a separate linear zone that follows the northern mountain front across most of the quadrangle. The zinc anomalies are mostly in Permian and Mesozoic rocks.

Antimony, arsenic, bismuth, and cadmium were not detected in any of the stream-sediment samples, and tin was detected only in one sample. Detectable quantities of these metals were also rare in the heavy concentrates. On the other hand, samples with anomalous barium are common except in the area of carbonate rocks in the northeastern part of the quadrangle.

The heavy mineral concentrates were scanned for thorium in addition to the elements reported in the published data (Cathrall and others, 1977a, b). Thorium was detected only in 20 samples, all of which are clustered around the areas of Permian rocks near the mountain front in the northeastern part of the quadrangle.

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