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GEOLOGIC REPORT NO. 39

Geology and Geochemistry of the Cosmos Hills, Ambler River and Shungnak Quadrangles, Alaska

By

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College, Alaska

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GEOLOGY AND GEOCHEMISTRY OF THE COSMOS HILLS, AMBLER RIVER AND SHUNGNAK QUADRANGLES, ALASKA

By

Crawford E. Fritts

A B S T R A C T

This report summarizes data concerning topography, glaciation, stratigraphy, structure, metamorphism, geologic history, geochemistry, and minerals of economic interest in the old Shungnak mining district. The data were collected during detailed geologic mapping in 1968 and 1969. The area studied is immediately north of Kobuk in western Arctic Alaska, and includes an exploration camp at Bornite. Bedrock geology is emphasized.

Several stratigraphic formations ranging in age from Devonian to Cretaceous form a complex window 20 miles long and 2 to 8 miles wide, which is bounded by at least four major overthrust faults. Each of these faults is characterized by a displacement of at least several miles. Three plates of allochthonous metamorphosed pelitic, volcanic, and carbonate strata, including more than 2000 feet of fossiliferous dolomitic limestone of Middle Devonian age, have been thrust over similar metamorphosed pelitic, volcanic, and subordinate carbonate strata of probable Devonian age. Early overthrust faulting was preceded by emplacement of granite of Early Cretaceous age, doming and folding, progressive regional and thermal metamorphism of low to moderate grade, and block faulting. A fourth and uppermost plate of allochthonous clastic rock of Cretaceous age was thrust over the older strata in latest Cretaceous or Early Tertiary time. The latest overthrust faulting was accompanied by emplacement and serpentinization of intrusive ultramafic rock and by low-grade dynamic or dynamo-thermal metamorphism of Cretaceous strata close to the uppermost thrust. Late high-angle faults of probable Tertiary age cut the thrusts at the eastern end of the window.

Minerals of current economic interest include copper sulfides and the nephrite variety of jade, but the area has produced placer gold and minor asbestos. Gold mineralization is believed to have preceded copper mineralization. Gold formerly mined from placers of Tertiary(?) to Pleistocene age was derived mainly from auriferous quartz veins that cut metamorphosed Devonian strata near intrusive granite of Early Cretaceous age. Copper sulfides are found mainly in dolomite breccia of Middle Devonian age close to major overthrust faults near Bornite. The copper probably is epigenetic in origin, but other possibilities are discussed briefly. The main copper deposit is believed to have assumed its present form and position during widespread hydrothermal activity associated with serpentinization of ultramafic rock emplaced during overthrust faulting in Late Cretaceous or Early Tertiary time. The source of the copper most likely was south or southwest of the Cosmos Hills. No indisputable evidence has been found to show that copper mineralization was related to the emplacement of granite or mafic rocks exposed in this area. Minor asbestos is found in serpentinite, and jade boulders derived from that rock are recovered from old placer tailings.

INTRODUCTION

PURPOSE AND SCOPE

The Cosmos Hills in western Arctic Alaska are geologically unique for three main reasons.

(1) They are the site of the only major anticlinal structure now known to be a window on the north edge of the Kobuk trough, which is one of seven geosynclines in Alaska containing Cretaceous strata.

(2) At Bornite, Paleozoic strata inside the Cosmos Hills window contain the largest recently publicized stratiform copper deposit in the State.

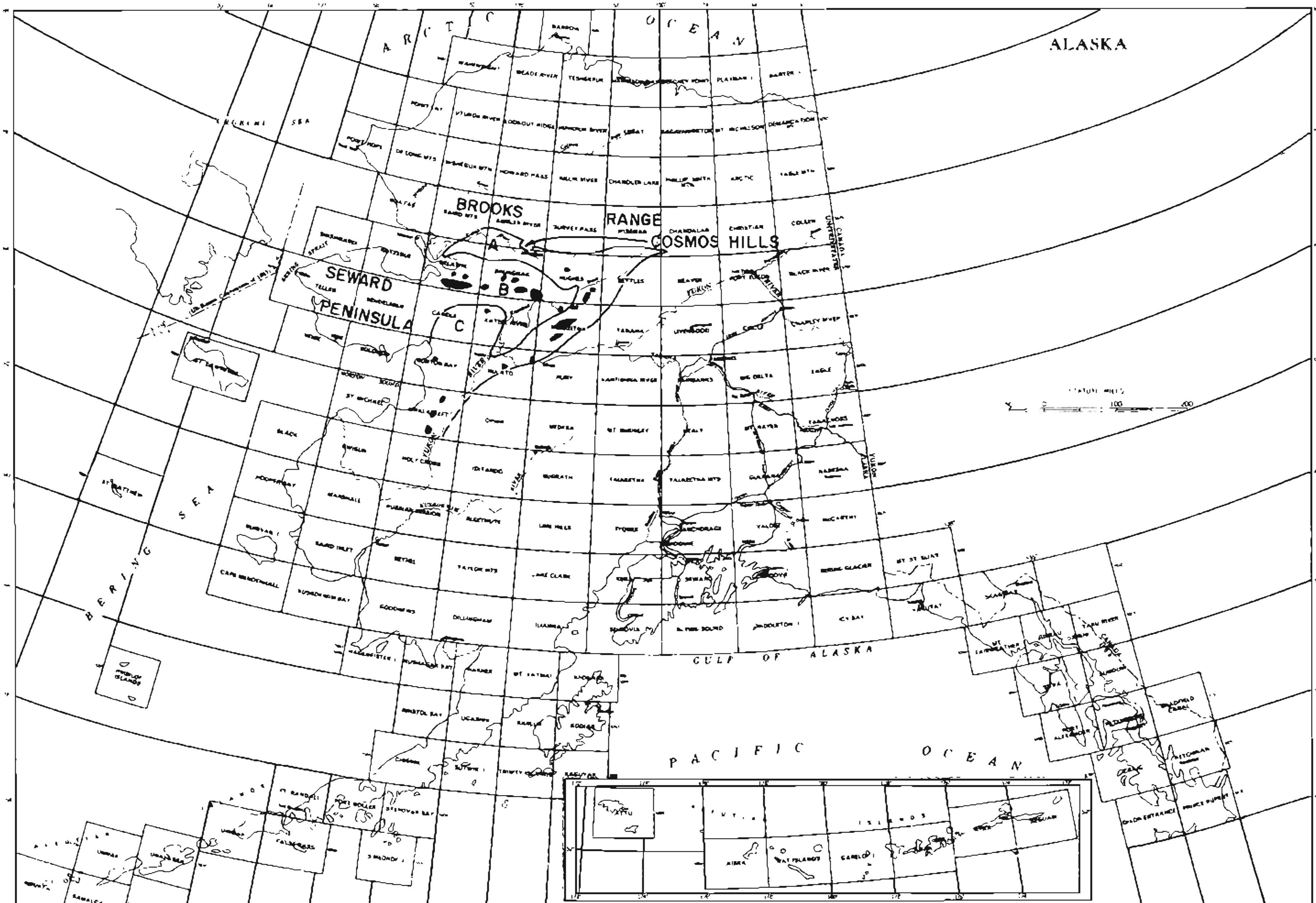
(3) These hills constitute most of the old Shungnak mining district, which contains abandoned gold placers and asbestos prospects as well as active jade claims. The variety of minerals of economic interest is but a small expression of the geological complexity of the area.

In 1968, the Alaska Division of Mines and Geology began a 2-year study of the Cosmos Hills in order to determine the relationship between regional geology and mineral deposits of economic interest in the Shungnak mining district. Special attention was given to stratigraphy, structure, igneous activity, metamorphism, and geologic history, because information about them can be of long range value in exploration for lode deposits. Topography, drainage, and glaciation also were studied, because they provide important clues concerning the geologic history of the area and the deposition of placer deposits.

This report describes the results of bedrock mapping and stream-sediment sampling in the Cosmos Hills during the summers of 1968 and 1969. It supplements ADMG Geologic Report 37 (Fritts, 1969), which primarily concerns work done by the Division in the southeastern part of the Cosmos Hills in 1968. Some of the data presented in that report are necessarily modified here in the light of new information obtained in 1969. Others are repeated for the sake of thoroughness, but photographs and tabulated geochemical data are not. By adding table 1 of Report 37 to the present report, the reader will have a single reasonably complete summary of the geology and geochemistry of the Shungnak mining district based on data available up to June 1970.

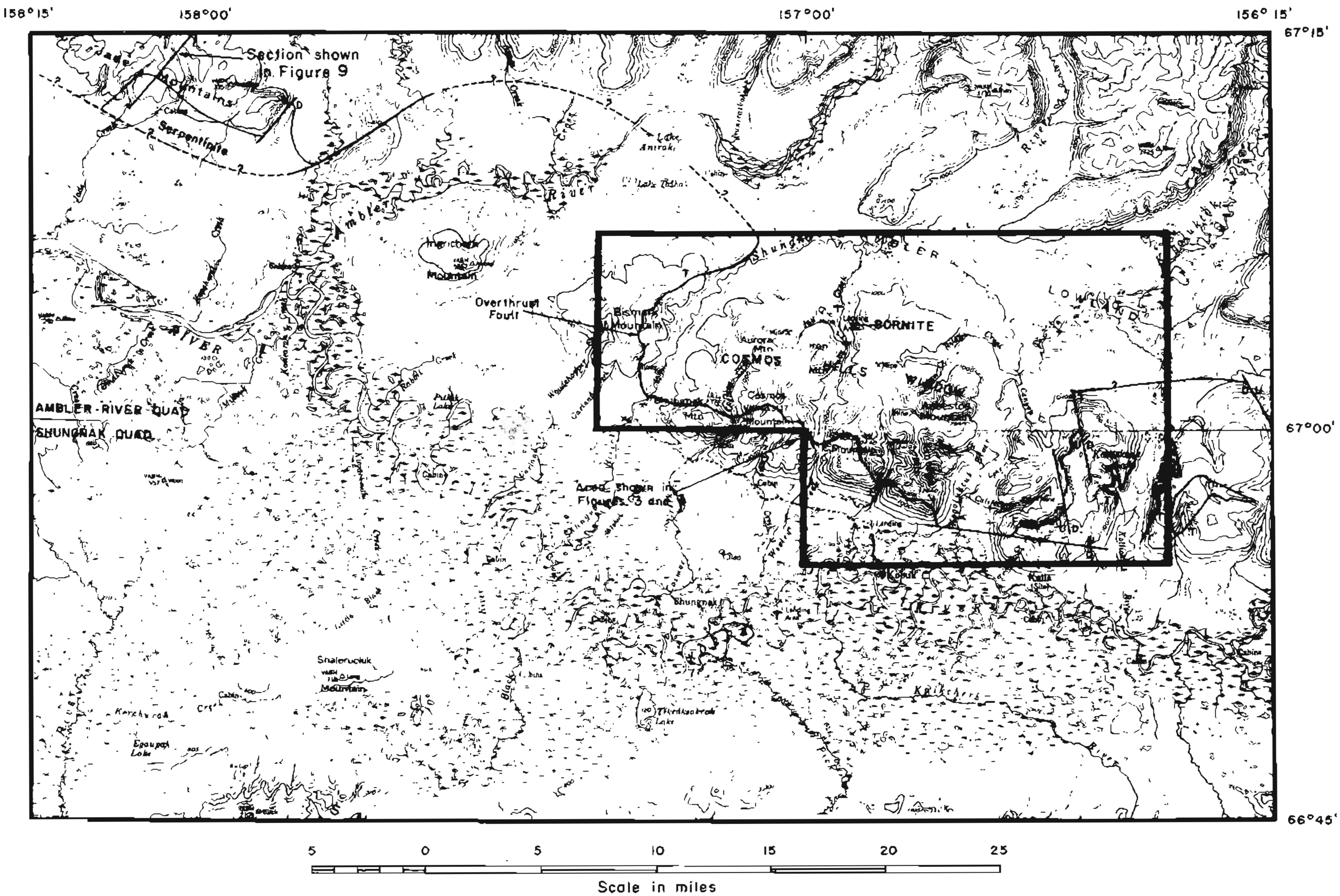
LOCATION AND ACCESS

The Cosmos Hills form an isolated highland 10 x 27 miles along the southern flank of the Brooks Range about 300 miles northwest of Fairbanks (*fig 1*). The highland extends east southeast across the boundary between the Ambler River and Shungnak quadrangles (*fig 2*). The Cosmos Hills are south of the Schwatka Mountains, east southeast of the Jade Mountains and west northwest of the Angayucham Mountains. The Cosmos Hills are approximately 4 miles north of the village of Kobuk. This village now contains about 50 residents, but formerly was much larger. For many years it was known as Shungnak, and was the main shipping and supply point for the Shungnak mining district. The site, however, commonly is flooded during spring breakup. In the late 1920's many residents left, and the village became known as Long Beach until at least 1931. The Kobuk post office, established in 1928, now is located here. The present village of Shungnak, which contains approximately 150 residents, is about 7 miles west of Kobuk. Bornite, the exploration camp of Bear Creek Mining Company and the Kennecott Copper Corporation, is about 11 miles north of Kobuk.



Map showing location of Cosmos Hills and outlines of (A) Kobuk trough, (B) Hogatza geanticline, and (C) Koyukuk geosyncline. (A) and (C) contain Cretaceous sediments. (B) has abundant Cretaceous volcanics. Black areas indicate Cretaceous granite. Paleozic rocks predominate in Brooks Range and on Seward Peninsula.

Figure I



Simplified geologic map showing the locations of the Cosmos Hills window, serpentinite in the Jade Mountains, and a major overthrust fault along the north edge of Cretaceous strata. Geology, in part, modified from Patton, Miller and Tailleur (1968).

Figure 2

Access to the mapped area is mainly by air, but partly by road and water. Gravel landing strips have been built at Dahl Creek, Kobuk, Shungnak, and Bornite. A good gravel road extends from Bornite to Dahl Creek and to the mining companies' Kobuk River Landing (*fig 3*). A poorer road extends from Dahl Creek to Kobuk, which is the easternmost point reached by tugboats and barges on the Kobuk River. Cat trails or unimproved roads lead to old placer workings and prospects near Dahl, California, and Cosmos Creeks, the Shungnak River, and Pardners Hill, but most are in poor condition. The eastern part of the area can be reached by canoe via the Kobuk and Kogoluktuk Rivers and by float plane via Kollioksak Lake and the Kogoluktuk when river levels are high. The western part of the area, however, is accessible mainly on foot or by helicopter. The Shungnak River is too shallow for float planes and too swift in deep canyons for canoes. The upper canyon (*fig 3*), for example, is characterized by nearly vertical walls 100 to 200 feet high and a roaring chute of unnavigable white water.

FIELD WORK

Field work was done on foot from four main camps on Dahl Creek and the Kogoluktuk and Shungnak Rivers (*fig 3*). Camps 1 and 2 were occupied in 1968. Brief reconnaissance west of Kollioksak Lake was accomplished at that time via float plane. Camps 1, 3, and 4 were occupied in 1969. Mapping then was facilitated by use of a Honda Trail-90 motorbike along the road from Dahl Creek to Bornite and on trails leading to Pardners Hill and the upper Dahl Creek placers. Camps 2 and 3 were reached by canoe and float plane, respectively. Moves from Camp 3 to Camp 4 and then to Kobuk were accomplished by helicopter, courtesy of Bear Creek Mining Company. Mapping in 1968 was done on published topographic base maps at scale 1:63,360 (1 inch = 1 mile). Mapping in 1969 and all compilations were done on scribecoat topographic base maps at scale 1:48,000 (1 inch = 4000 feet). The final map was redrafted for publication at a reduced scale.

ACKNOWLEDGEMENTS

Numerous people facilitated the recent work. Christopher P. Cameron and Samuel W. Corbin were geological field assistants responsible for all geochemical sampling in 1968 and 1969, respectively. They also did some of the geologic mapping. We are especially grateful to Bear Creek Mining Company, Kennecott Copper Corporation, Bernhardt Air Service, Wien Consolidated Air Lines, and residents of Kobuk and Dahl Creek for courtesies and assistance during both field seasons. Individuals who deserve special mention include: D. M. Snyder, C. G. Bigelow, Richard Walters, and Keith Marple of Bear Creek Mining Company; A. A. Dundas and Paul Mogenson of Kennecott Copper Corporation; Mr. and Mrs. Anthony Bernhardt, Mr. and Mrs. Guy Moyer, and Michael Tickett of Kobuk; and Mr. and Mrs. James Edsall, William Munz, Ivan Stewart, and C. E. Stout of Dahl Creek. Bigelow, geologist-in-charge at Bornite, showed continual interest in our work, engaged in several technical discussions with the writer, and arranged for brief helicopter support in 1969.

Members of the U. S. Geological Survey also have been helpful. I. L. Tailleur, W. P. Brosge, W. W. Patton, Jr., R. B. Forbes, C. L. Sainsbury and others have discussed various aspects of the geology of the Brooks Range and Seward Peninsula. Tailleur also loaned the writer preliminary maps and other data accumulated during geological reconnaissance in and near the Cosmos Hills. J. T. Dutro, Jr., and J. W. Huddle studied crinoid-bearing limestone collected by the writer at Ferguson Peak in 1968. Dutro also studied other fossils collected by the writer in the Ambler River quadrangle in 1969. Geochemical samples collected in 1968 were analyzed at a USGS field laboratory in Anchorage.

Assistance and suggestions by colleagues in the Alaska Division of Mines and Geology also are appreciated. The writer has benefited from numerous discussions of the geolgy of the Brooks Range and Seward Peninsula with E. R. Chipp and Gordon Herreid, respectively. Atomic absorption and X-ray analyses of samples collected in 1969 were done by Namok Cho and Michael Mitchell in the Division laboratory at College. Hand samples were photographed by G. R. Eakins. Final drafting was done by Charlotte Renaud.

The Minerals Industries Research Laboratory at the University of Alaska performed 30-element spectrographic analyses of stream sediment samples collected in 1969. A computer program was devised by Lawrence E. Heiner to handle such data.

PREVIOUS WORK

Exploration, prospecting, mining, and geological reconnaissance in and near the Cosmos Hills have been mentioned in more than 60 reports since 1884. However, many references are brief, and at least 15 are unpublished. The available literature has been summarized by the writer in annotated bibliographies concerning (1) copper, (2) gold, and (3) serpentinite, asbestos, and jade. They are filed at the office of the Division of Mines and Geology in College. The more important references were discussed in ADMG Geologic Report 37. These and others are categorized below.

Exploration in 1884-1886 by the U. S. Navy along the Kobuk (formerly Kowuk or Kowak) River was discussed by Cantwell (1884, 1885) and Stoney (1900). No geological work was done, but the authors described trips to the Jade Mountains about 20 miles west northwest of the Cosmos Hills, in search of jade (*fig 2*). Samples were described by Merrill (1885) and Clarke and Merrill (1888).

The gold rush of 1898 brought hundreds of prospectors to the Kobuk River region, approximately 800 of whom established winter camps along the river. The activities and frustrations of one group of 20 men from San Pedro, California, were recorded by Grinnell (1901). This group established two winter camps. One was on the Kobuk near the mouth of the Hunt River. The other was on the Kogoluktuk River in the Cosmos Hills. Like most other prospectors in the region, however, the group left for home by way of Nome in the spring of 1899.

Work by the U. S. Geological Survey in the Cosmos Hills has included geological reconnaissance, the preparation of brief progress reports on placer gold production, and short investigations of other mineral deposits. Initial reconnaissance was undertaken by Mendenhall (1902), who descended the Kobuk River by canoe in August 1901. The best early description of the general geology and placers of the area was prepared by Smith and Eakin (1911). These authors named the Cosmos Hills for Fort Cosmos, a winter camp established by Stoney in 1885 near the mouth of the present Cosmos Creek. Smith (1913) and Smith and Mertie (1930) repeated almost verbatim much of the data recorded by Smith and Eakin. Statistical data concerning placer mining and gold production were recorded by Brooks (1905, 1906), Brooks and others (1909, 1910, 1912, 1913, 1914, 1916, 1921, 1922, 1924, 1925), Martin and others (1919), Cathcart (1920), Moffitt and others (1927), Smith and others (1929, 1930a, 1930b, 1932, 1933), and Smith (1933, 1934a, 1934b, 1936, 1937, 1938, 1939a, 1939b, 1941, 1942). Asbestos-bearing serpentinite at Asbestos Mountain was mapped and described by Coats (1943). Early copper prospects near Bornite were described by Brooks and others (1909) and Smith and Eakin (1911). Uranium mineralization there was discussed by White (1950), Wedow (1956), and Matzko and Freeman (1963). Surficial geology was mapped and described by Fernald (1964). Data concerning metallic mineral resources were summarized by Berg and Cobb (1967) and Cobb (1968a, 1968b). Modern reconnaissance geologic mapping at scale 1:250,000 (1 inch = 4 miles) was done by Patton, Miller, and Tailleur (1968), who also recorded the latest paleontological and radiometric data concerning the ages of rocks in and near the Cosmos Hills. Their map has been especially useful in planning subsequent detailed geologic mapping.

The U. S. Bureau of Mines sampled asbestos-bearing serpentinite near Bismark Mountain in 1944 and near Shungnak and Asbestos Mountains in 1945 and 1946. Preliminary work was reviewed by the U. S. Bureau of Mines (1944) and Bain (1946). The general geologic setting of the asbestos deposits and the methods and results of sampling were described by Heide, Wright, and Rutledge (1949), who published the map of Asbestos Mountain prepared by Coats (1943).

Work by the Alaska Territorial Department of Mines involved mainly examinations and descriptions of certain mineral deposits, prospects, and mining operations. Wimmler (1925) mentioned placer mining in the Shungnak district in 1925. Reed (1932) prepared a much more complete summary of gold placers, mining, and prospecting in the Cosmos Hills as of 1931. Anderson (1945, 1947) briefly described copper, jade, and asbestos deposits in this area and in the Jade Mountains. Saunders (1953, 1955, 1956, 1963) examined copper prospects at Ruby Creek and Pardners Hill, and noted that "jade" boulders were being recovered from Dahl Creek as early as 1952.

Bear Creek Mining Company, a subsidiary of Kennecott Copper Corporation, began detailed exploration for copper near Ruby Creek (Bornite) and Pardners Hill in 1957 after several years of prospecting had been done by Rhinehart Berg and his associates. The recent work has included site mapping, trenching, diamond-drilling, geochemical sampling, geophysical surveying, and limited underground exploration. Bear Creek also engaged in regional exploration and reconnaissance mapping. Read and Lehner (1959) mapped the bedrock geology of the Cosmos Hills at scale 1:125,000 (1 inch = 2 miles). The general geologic setting and various aspects of mineralization and exploration at Bornite were discussed by Chadwick (1960), Lund (1961), Lutz (1963), and Runnells (1963, 1964, 1965, 1966, 1969). Detailed stratigraphic studies by C. G. Bigelow were acknowledged by Runnells (1963, p 27), but remain largely confidential. The report by Read and Lehner (1959) also is confidential and has not been read by the present writer.

Detailed geologic mapping and geochemical sampling by the Alaska Division of Mines and Geology in the southeastern part of the Cosmos Hills were discussed by Fritts (1969). The author mapped and described four main stratigraphic formations ranging in age from Middle Devonian or older to Late Cretaceous. He accepted most of the geologic ages assigned to those rocks by Patton, Miller, and Tailleur (1968), but showed that a unit of metabasalt and related rocks above Middle Devonian dolomitic limestone probably is Devonian rather than Jurassic(?) in age. He also showed that geologic structure and geologic history in the area are more complex than previously supposed. Reinterpreting some of the data recorded by previous authors, he concluded that the principal geologic structure in the Cosmos Hills is a window bounded by two major low-angle overthrust faults rather than a doubly-plunging anticline bounded by two major unconformities. Geochemical data showed that copper mineralization probably did not accompany emplacement of granite of Early Cretaceous age in this area. The author tentatively accepted the Jurassic(?) age previously assigned to local serpentinite by Patton, Miller, and Tailleur (1968) but added a note to the map explanation indicating that a Late Cretaceous or younger age is required by field evidence found in the Ambler River quadrangle in 1969. Field evidence found at that time also showed that geologic structure in the area is even more complex than realized in 1968.

The author would like to correct the following omissions from Geologic Report 37:

Table 1 (1) Footnotes were to have been numbered to specifically acknowledge Miller and Tripp for atomic absorption analyses, and Curry and Martinez for spectrographic analyses.

Figure 2a (1) Circles shown at Stout Mountain and Ferguson Peak were to have contained the letter F to designate fossil localities. The entire symbol was omitted from the map explanation.

(2) Near Juanita Creek, sec. 23, T. 18 N., R. 10 E., labels were omitted from a small body of serpentinite (Js) adjacent to an overthrust fault, and from a limestone (Pzc) north of the fault.

(3) Near Glacier Creek, sec. 7, T. 18 N., R. 10 E., labels were omitted from small bodies of limestone (Pzc) and greenstone (Pzg) in the southwestern and northwestern parts of the section, respectively.

(4) Near Lynx and California Creeks, secs. 16 and 22, T. 18 N., R. 10 E., labels were omitted from small bodies of limestone (Pzc).

S U R F I C I A L   G E O L O G Y

TOPOGRAPHY AND DRAINAGE

The Cosmos Hills are characterized by moderately rugged mature topography and approximately 3000 feet of relief. Inerevuk Mountain, the tallest peak, is 3440 feet high. This mountain and several others that exceed 2600 feet along the western, southern, and eastern edges of the main highland are underlain by continental strata of Cretaceous age, which help frame the Cosmos Hills window. Inside this semi-rim, most hills consist mainly of marine strata of Paleozoic age and do not exceed 2440 feet. However, Black Rock Ridge, which is capped by resistant greenstone, reaches 2960 feet. In contrast, the elevations of Camps 1 to 4 range from 250 to about 500 feet.

Major rivers in the Cosmos Hills and Angayucham Mountains and in the adjacent Schwatka Mountains of the Brooks Range all flow south-southwestward away from but nearly perpendicular to the range. Drainage in the map area is primarily south-southwestward via the Shungnak and Kogoluktuk Rivers, although several streams such as Ruby Creek flow northward before joining these rivers. All of the major river valleys are relatively straight where they pass through mountainous terrain, and those of the Cosmos Hills are in line with counterparts in the Schwatka Mountains. After leaving those mountains, however, several rivers swing westward 5 to 15 miles through the west-plunging Ambler Lowland before passing through the Cosmos Hills and equivalent highlands (*fig 2*). This change in course is believed to be due primarily to slight uplift of the Cosmos Hills and Angayucham Mountains relative to the Schwatka Mountains of the Brooks Range in Tertiary or Quaternary time. The local drainage also is influenced to some extent by the presence of glacial drift of Pleistocene age (Surficial deposits and glaciation). The physiographic evidence at hand suggests that the valleys now occupied by the Shungnak and Kogoluktuk Rivers and Kollioksak Lake in the Cosmos Hills formerly were occupied by the Ambler, Shungnak, and Kogoluktuk Rivers, respectively.

The straightness of the major river valleys and their relationship to the trend of the Schwatka Mountains of the present Brooks Range clearly indicate that they are antecedent valleys formed during a pre-glacial episode of erosion. Their south-southwest trends reflect original consequent drainage directly related to the uplift of the ancestral Brooks Range, which probably resembled the present Alaska Range in altitude and relief during much of Cretaceous time (Structure and geologic history). The valleys now occupied by Cosmos Creek and by Wesley and Ruby Creeks are parallel to adjacent major river valleys. The creek valleys, however, seem oversize for the streams that now occupy them. They most likely were started by streams of the original consequent drainage system of the ancestral Brooks Range before the Cosmos Hills were isolated from the Schwatka Mountains by erosion.

Downcutting by the major rivers presumably has been contemporaneous with intermittent regional deformation since latest Jurassic or earliest Cretaceous time. The original consequent drainage system probably began with initial elevation of the Brooks Range geanticline in Late Jurassic time (Payne, 1955). In the Cosmos Hills, orogenic activity reached a climax during Early to Late Cretaceous time, when extensive overthrust faulting accompanied(?) or followed the emplacement of granite now believed to be about 120 million years old (Granite and structure). Renewed orogenic activity during latest Cretaceous or Early Tertiary time perhaps 50 to 70 million years ago involved overthrust faulting of Early to Late Cretaceous strata, which had been derived from the ancestral Brooks Range. Thus the major south-southwest-trending valleys in the Cosmos Hills and Schwatka Mountains probably have existed for 50 to 100 million years or more, while the mountains through which they pass were being eroded.

In summary, the present mature topography in the Cosmos Hills appears to be largely the result of some 50 million years of erosion after deformation of Cretaceous strata but before glaciation of the Brooks Range and vicinity. Isolation of the Cosmos Hills from the Schwatka Mountains is believed to have been accomplished long before the end of Tertiary time.

SURFICIAL DEPOSITS AND GLACIATION

Surficial deposits in or near the Cosmos Hills include (1) glacial drift of pre-Wisconsin age along the southern, western, and northern flanks of the highland, (2) drift of Wisconsin(?) age near Kollioksak Lake, the upper part of the Kogoluktuk River, and the northern flank of the highland, (3) stabilized dune sand along the southern edge of the highland between Cosmos Creek and the Kogoluktuk River, (4) terrace gravels along parts of the Shungnak and Kogoluktuk Rivers, and (5) miscellaneous materials such as colluvium, alluvium, and soils. The general distribution of major units is shown by Fernald (1964) at scale 1:250,000 (1 inch = 4 miles). Some of the data discussed below are taken from his report.

Early (Kobuk) glaciation in pre-Wisconsin, perhaps Illinoian, time is indicated by the oldest drift. This material is highly dissected and does not show recognizable morainal form. It is well exposed, however, in scraped areas near Camp 1. It also has been mapped to altitudes of 400 to 800 feet along the flanks of the Cosmos Hills (Fernald, 1964, pl 1). This drift is believed to have been deposited by ice that originated in the Schwatka and Baird Mountains of the Brooks Range.

The maximum extent and thickness of the "Kobuk" ice are unknown, but field evidence indicates a minimum thickness of about 2000 feet in at least the northern part of the map area. Erratic boulders are scattered over many of the hills in the vicinity of Bornite at altitudes as high as 2200 feet. They are especially obvious at Pardners Hill, where garnetiferous metadiabase boulders as much as 3 feet in diameter derived from the Brooks Range lie on less metamorphosed metasedimentary rocks. Similar boulders also were found irregularly distributed through colluvium at the Riley Creek placer near Shield Mountain (Smith and Eakin, 1911, p 295). No erratic boulders, however, were noticed by the present writer on hills more than 2200 feet high.

The general scarcity of glacial debris above 800 feet altitude and its apparent absence above 2200 feet suggests the following possibilities:

(1) Ice of the Kobuk glaciation may not have been much more than 2000 feet thick in this area.

(2) If thicker, the ice may not have carried much of a load at elevations greater than 2200 feet.

(3) The ice may have tended to flow around rather than across obstacles such as the Cosmos Hills.

(4) Erosion since Kobuk time may have removed most of the glacial debris from these hills, although such erosion apparently was not strong enough to destroy the evidence of original consequent drainage discussed above.

A younger (Ambler) glaciation in Wisconsin(?) time is indicated by abundant drift in the Ambler Lowland and by subdued moraines deposited by valley glaciers along the Shungnak and Kogoluktuk Rivers and near Kollioksak Lake. No clearcut evidence for other valley glaciation in the Cosmos Hills was found during the recent mapping. The "V" shape of much of the Dahl Creek valley, for example, clearly indicates that this part of the valley was not scoured by moving ice, and morainal features are lacking in the broader uppermost part. Any ice that occupied that valley must have been either stagnant or too thin to scour the valley appreciably. The area contains no obvious cirques, although the northern flanks of peaks such as Inerevuk and Cosmos Mountains are steep. Three small patches of drift shown by Fernald (1964, pl 1) on the east side of Fish Hook Ridge on the basis of aerial reconnaissance and photo interpretation were not confirmed on the ground.

B E D R O C K   G E O L O G Y

INTERPRETATION OF STRATIGRAPHY AND STRUCTURE

The interpretation of stratigraphy and structure in this report is based mainly on personal observation of many bedrock outcrops in all except the northernmost part of the Cosmos Hills, supplemented by other available data. The writer did not have access to most of the unpublished detailed stratigraphic and structural information recorded by mining companies, but in 1969 he did have copies of the map compiled by Read and Lehner (1959) and other unpublished maps loaned to him by I. L. Tailleur. Data shown on figure 4 north of latitude 67°05'N are modified from those maps. Information concerning bedding and lithology in a few other places in the area also were obtained from those maps, because it was impossible to visit every outcrop in the time available. The writer, however, assumes full responsibility for the placement and interpretation of all data shown on the present geologic map and cross sections. Geology east of Kollioksak Lake is modified from Patton, Miller, and Tailleur (1968).

Mapping in the Cosmos Hills is hampered by (1) the lack of outcrops in areas covered by forest, tundra, or other surficial materials, (2) the presence and repetition of only a few distinct lithologies such as phyllite, greenschist, and limestone in thousands of feet of geosynclinal strata, (3) the lenticular nature of thin stratigraphic units, and (4) the distortion of bedding as a result of folding, faulting, metamorphism, and severe frost action. Thus the mapping and interpretation of stratigraphy and structure involve a certain amount of prejudgement. Stratigraphic units thousands of feet thick, for example, normally persist for miles along strike unless they are faulted, folded, displaced by intrusive rocks, covered by younger formations, removed by erosion, or were deposited on extremely irregular surfaces. In the present report, the writer merely attempts to recognize stratigraphic and structural units that seem logical and consistent with available field evidence, but many problems remain.

In general, each new geologic map of the area has shown that bedrock geology is more complex than previous maps suggest, and this trend undoubtedly will continue. We now know that the Cosmos Hills, like most of the southern Brooks Range, are characterized by imbricate overthrust faults, which have greatly complicated the stratigraphic and structural picture. If outcrops were more numerous or the area were mapped at a larger scale, even the present rather complex map and cross sections probably would seem oversimplified. This is especially true along the crest of a major anticline within the Cosmos Hills window. South of Pardners Hill and Shield Mountain, for example, thin limestone units mapped immediately north of the fold axis appear to be absent south of the axis. This may be the result of displacement along faults that are not recognized where bedrock is predominantly interbedded phyllite and greenschist. It also is quite likely that some displacement has occurred along certain stratigraphic boundaries. In the field, thin well exposed limestones such as the one shown south of Pardners Hill appear to be distinct mappable stratigraphic units of rather consistent thickness and trend, but in some places they display markedly discordant bedding oblique to their mapped boundaries (*compare figs 4A and 5*). At other places, such as the west end of the main anticline and the vicinity of Bornite, queried overthrust faults are inferred where structural discordances are apparent or where the presence of overthrust faults seems possible but uncertain.

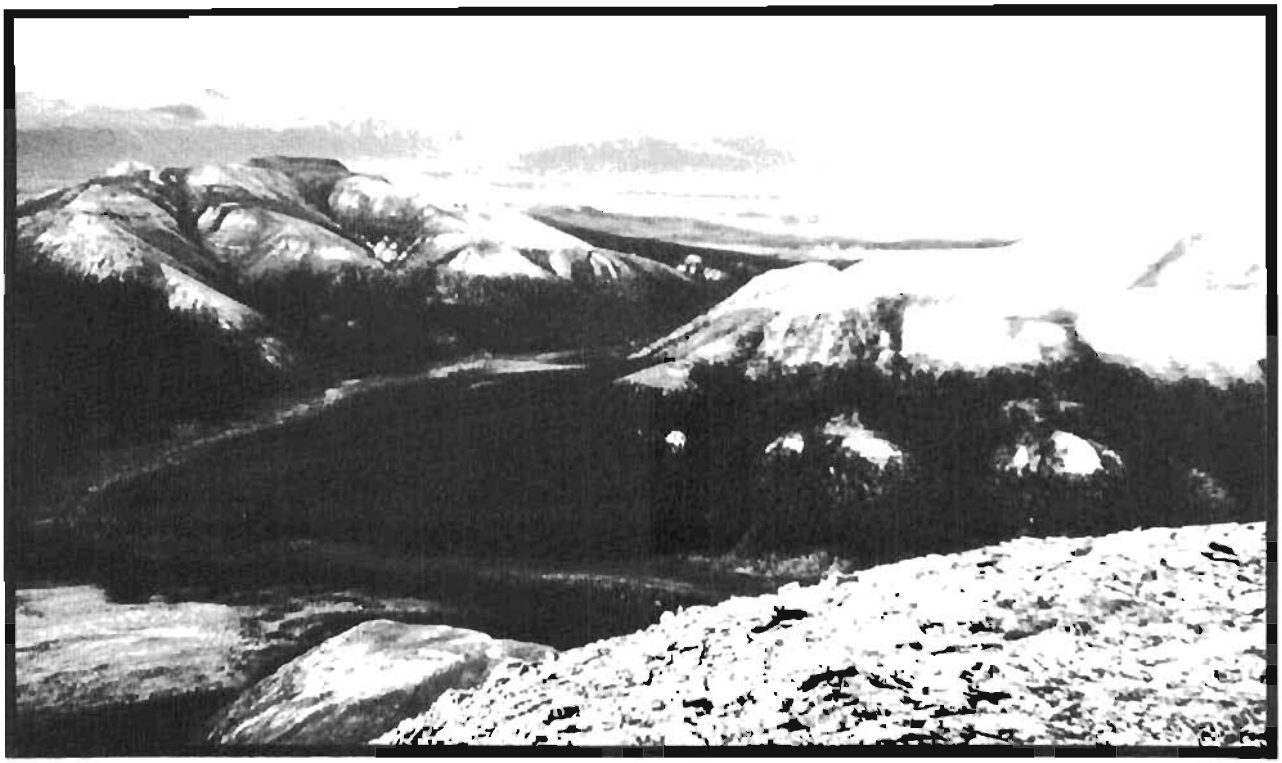


Figure 5. Aurora Mountain and Pardners Hill viewed from Cosmos Mountain. At Aurora Mountain, thin klippe of dark gray phyllite overlies light gray limestone and dolomite. At Pardners Hill, thick klippe of light gray limestone and dolomite overlies phyllite and thin limestone unit exposed in wooded area. Brooks Range and Ambler Lowland in background.

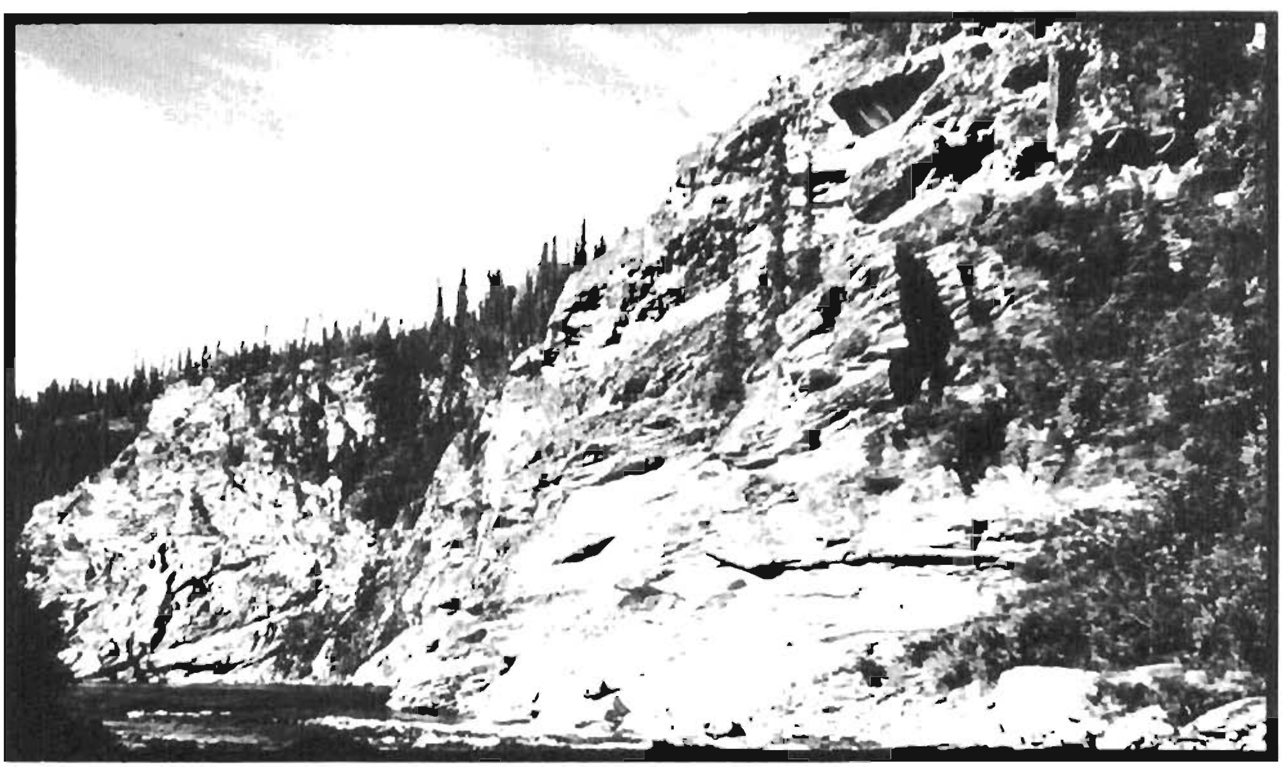


Figure 6. White marble with interlayered greenschist on west wall of upper canyon of Shungnak River near Marble Creek, Cosmos Hills.

In the following section concerning stratigraphy, major map units are discussed in the approximate order oldest to youngest (lowermost to uppermost) shown on the map explanation (*fig 4C*). However, the reader should bear in mind that only the thick dolomitic limestone, Pzd, has been dated well by fossils. It is quite possible that interbedded phyllite and greenschist of one thrust slice may be grossly equivalent to phyllite and greenschist, respectively, of another. It also is possible that massive greenstone in one place is the intrusive equivalent of greenschist in another, but greenstone is discussed with adjacent strata for convenience.

STRATIGRAPHY

Paleozoic Rocks

Phyllitic schist and related rocks (Pzs, Pzc, Pzt, Pzg)

The lowest stratigraphic formation consists of weakly to moderately metamorphosed pelitic, calcareous, and volcanic strata. It includes a predominant graywacke-bearing, phyllitic schist unit (Pzs), small to large units of crystalline limestone and marble (Pzc), and small to large units of greenschist and greenstone of probable metavolcanic origin (Pzt, Pzg). In some outcrops, these rocks are all intimately interlayered or interbedded. The formation underlies at least 65 square miles in the central part of the Cosmos Hills and is more than 5000 feet thick.

Phyllitic schist (Pzs) -- Thinly bedded, graywacke-bearing phyllite and schist underlie approximately 50 square miles in the mapped area. Beds less than one inch to more than one foot thick are obvious in many outcrops, especially where the rocks are most thoroughly metamorphosed. The bedding is recognized primarily by variations in the amount of muscovite and quartz in the rock matrix. Foliation commonly parallels bedding. In the western part of the area, this unit also contains numerous tuffaceous beds and layers of greenschist similar to unit Pzt, but most are too small and poorly exposed to be mapped separately.

Typical pelitic rocks such as phyllite and muscovite schist are characteristic of this unit. The rocks consist mainly of muscovite, albite, and quartz, with small amounts of chlorite and carbonate. Garnet and biotite are present in beds of appropriate composition and metamorphic grade, but biotite is not plentiful. The abundance of muscovite and albite in the rocks indicates a high content of K and Na, respectively, and the comparatively small amount of chlorite and biotite in them indicates a low Mg and Fe content. Typical accessory minerals are sphene, tourmaline, apatite, zoisite, clinozoisite, rutile, hematite, pyrite, and pyrrhotite. The pyrrhotite is most obvious in quartz-rich schist exposed near Camp 4 and in the bed of California Creek immediately east of massive greenstone (Pzg). The pyrrhotite is not known to be nickeliferous. The mineral forms lenses as much as 5 mm long parallel to foliation (bedding) and lineation, and pre-dates regional metamorphism. Similar accessory pyrrhotite in phyllite at Bornite has been described by Runnells (1963).

The pelitic rocks are characterized by abundant carbon and a gradual but conspicuous increase in metamorphic grade from the central to the eastern and western parts of the area. Medium-dark-gray to black carbonaceous phyllite is characteristic of this unit in the vicinity of Ruby Creek. The phyllite there contains neither garnet nor albite porphyroblasts. However, both are abundant in beds of appropriate composition near the Kogoluktuk River, and albite is locally abundant near the Shungnak River. Near intrusive granite exposed along the Kogoluktuk, the predominant rock is fine- to medium-grained muscovite schist containing either garnet or albite porphyroblasts 1-10 mm in diameter, or both. Similar albite porphyroblasts also are abundant in pelitic rocks exposed near Camp 4 and the upper canyon of the Shungnak River. In general, albite is much more abundant than garnet, as indicated by the relative abundance of symbols A and G, respectively, in the phyllitic schist unit (Pzs) on the geologic map (*fig 4*). Most of the albite porphyroblasts contain enough carbon to make them nearly black, and they strongly resemble ferromagnesian minerals such as hornblende, except for a stubby crystal habit and a lack of acute-angle prismatic cleavage. Both kinds of porphyroblast increase in size and abundance toward intrusive granite and might be used as indicators of proximity to such rock during exploration. However, no granite is exposed near the Shungnak River in this area.

The quartz content of the phyllite and schist varies widely. In some places, matrix quartz is so abundant that the rock becomes metagraywacke or impure quartzite, which forms distinct beds 1 to 6 inches thick. The quartz-rich rock commonly is carbonaceous, dark, tough, slabby, and breaks with a nearly conchoidal fracture. It is most conspicuous in prominent outcrops on the west side of the Kogoluktuk River about ½ to 1 mile from granite (Kg) and on both sides of a tributary stream west of Wesley Creek near Ruby Pond. In addition, thinly bedded, noncarbonaceous, nearly white quartzite crops out near the center of sec. 11, T. 18 N., R. 10 E. (from the Kateel River reference point) where quartz-rich rock is associated with noncarbonaceous actinolite schist.

Crystalline limestone (Pzc) -- Impure crystalline limestone and marble form widely scattered beds from less than 1 foot to several hundred feet thick within the perdominant phyllite and schist. Where least metamorphosed, the typical limestone is gray, thinly bedded, well lineated, slightly micaceous calcarenite. It effervesces well in dilute hydrochloric acid and apparently consists mainly of calcite. It commonly contains minor muscovite and quartz. Where moderately metamorphosed and associated with greenschist, the rock also contains tremolite or actinolite and clinozoisite. Accessory pyrite is present in some outcrops. Unmapped, metamorphosed, dolomite breccia 15 feet thick and other carbonate rocks are exposed in a vertical cliff on the east side of the Shungnak River at Camp 4. The breccia consists of gray dolomite fragments set in a matrix of white calcite, which contains abundant pyrite. The dolomite fragments display scattered black albite porphyroblasts as much as 3 mm in diameter. White to gray tremolite-bearing marble exposed in the upper canyon of the Shungnak River (*fig 6*) also is assigned tentatively to this map unit, although the stratigraphic position of the marble is uncertain. The marble at that locality contains layers of greenschist ½ inch to 40 feet thick, which probably represent metamorphosed intrusive rocks and (or) tuffs.

Greenschist (Pzt) -- Noncarbonaceous, porphyroblastic actinolite schist (greenschist) was mapped separately as a generalized unit only in sec. 11, T. 18 N., R. 10 E., but similar less metamorphosed greenschist is locally abundant near Lone Mountain and Razorback Ridge. The mapped greenschist contains numerous needle-like crystals of actinolite, which give the rock its characteristic greenish-gray color and satiny luster. It also contains numerous porphyroblasts of white to creamy albite 1-5 mm in diameter. These crystals contain many tiny inclusions of other minerals, but differ from the black albite porphyroblasts described above by lacking carbon. The rock also contains chlorite, muscovite, quartz, epidote, and minor biotite and carbonate. Accessory minerals are sphene, apatite, pyrite, and magnetite.

The actinolite schist and related greenschist are interpreted here as metatuff. The rock is intimately interlayered or interbedded with phyllitic schist, metagraywacke, and minor impure quartzite. Beds range from less than one inch to more than one foot thick. The interbedding of pelitic rocks and actinolite schist is believed to reflect contemporaneous deposition of mud and volcanic ash, respectively.

Greenstone (Pzg) -- Tough, massive greenstone, with subordinate schist, metagraywacke, and greenschist similar to the rocks described above, forms large generalized bodies underlying about 2 square miles near Crescent Ridge and about 7 square miles in the vicinity of Black Rock Ridge. This rock is resistant to erosion and caps prominent hills which are littered with numerous subangular boulders of greenstone as much as 10 feet in diameter. Several small bodies of similar rock also crop out within the main area occupied by phyllite and schist. The typical greenstone consists mainly of green hornblende or actinolite, epidote, chlorite, albite, and quartz. Garnets 1-10 mm in diameter are abundant near Crescent and Black Rock Ridges, where the metamorphic grade of the rock is moderately high for this area. In contrast, near Harry Creek, where the metamorphic grade is lower, garnet has been observed only as numerous tiny crystals in unusually heavy, thinly bedded, impure quartzite within the greenstone in the SW¼, sec. 1, T. 18 N., R. 9 E. Near the summit of Black Rock Ridge, the greenstone locally is gray and contains numerous black hornblende porphyroblasts a few millimeters in diameter. In the same area, dashed lines shown within this map unit (*fig 4A*) mark the approximate positions of black amphibole-bearing, highly carbonaceous quartz-muscovite rock a few tens of feet thick, which seems to separate much larger layers of massive greenstone. In some places, the greenstone itself contains small amounts of muscovite and carbonate, and it is interlayered with distinct mappable units of thinly bedded crystalline limestone. Accessory minerals in the greenstone are sphene, pyrite, hematite, and magnetite.

Previously the main greenstone in the Shungnak quadrangle was interpreted as a domed, faulted, and partly eroded stratigraphic unit 600 to 1000 feet thick composed of metatuff perhaps interbedded with metabasalt, although the possibility of an intrusive origin also was mentioned (Fritts, 1969, p 8). Now it is certain that at least part of the massive greenstone represents metamorphosed intrusive gabbro or basalt. At the summit of Black Rock Ridge, the greenstone contains a large isolated block of crystalline limestone several tens of feet in diameter, which appears to be a xenolith or inclusion within a metamorphosed intrusive mafic igneous rock. Furthermore, the base of the generalized greenstone map unit appears to cross stratigraphic boundaries near and southwest of Black Rock Ridge. On the other hand, the presence of distinct beds and layers of metasedimentary rock such as schist, metagraywacke, crystalline limestone, and greenschist (metatuff) within the largest greenstone map unit still suggests contemporaneous sedimentation and volcanic activity in a marine environment. Thus the largest greenstone map unit is interpreted here as a complex mixture of metamorphosed intrusive and extrusive mafic igneous rocks interlayered with subordinate metasedimentary rocks. The total thickness of the predominantly metavolcanic rocks now is believed to be at least 1500 feet and possibly more than 4000 feet (*cross sections A, G, and H, fig 4B*).

Geologic age -- The age of this formation is uncertain, but is believed to be Paleozoic. No fossils were found in it during or before the recent mapping. However, it underlies a thick fossiliferous dolomitic limestone (Pzd) of known Devonian and probable Middle Devonian age, parts of which are lithologically similar to the limestone (Pzc) described above. Although the dolomitic limestone (Pzd) now is known to have been thrust over the phyllitic schist (Pzs), the similarity between thinly bedded limestones and between pelitic rocks of both formations suggests a similarity in age. On the other hand, the marked difference in predominant lithology between the two formations reflects a difference in environments of deposition, and it is possible that the phyllitic schist and related rocks are pre-Middle Devonian in age. The age of this formation, therefore, is reported here as Middle Devonian or older.

Main dolomitic limestone and related rocks (Pzd, Pzdp, Pzdg)

A thick sequence of weakly to moderately metamorphosed limestone, dolomite, dolomite breccia, and subordinate pelitic and mafic volcanic rocks underlies more than 20 square miles in the northern, western, and southern parts of the map area. These rocks crop out mainly in a belt from less than 1000 feet to more than 2 miles wide along the edges of the Cosmos Hills window, but parts of the same formation are well exposed at Aurora Mountain, Pardners Hill, and Lone Mountain (*cover photo and fig 5*). The formation now is known to be allochthonous and is characterized by locally strong internal deformation and high-angle faults. However, it appears to be thickest and least deformed in the area north of Shield Mountain, where its thickness is at least 2000 feet and may exceed 2500 feet (*cross sections E and F, fig 4B*). The position of the northern boundary of this formation at Aurora Mountain is uncertain, due to a lack of outcrops. It is possible that the carbonate rocks exposed there are continuous with rocks of the same map unit exposed west of the Shungnak River and south of Cockscomb Ridge.

Dolomitic limestone (Pzd) -- The predominant carbonate rocks of this formation were mapped as dolomitic limestone, although distinct units of limestone, dolomite, and dolomite breccia can be recognized in the field. At the present map scale, the writer has attempted to show only major divisions of this map unit. In the area north of Shield Mountain, for example, a line was drawn along the southern flank of an east-trending series of prominent ridges and knobs of dolomitic reef breccia and related rocks, which appear to constitute a good stratigraphic marker unit within the main carbonate formation. This line marks the approximate boundary between lower and upper parts of the formation in that area (*fig 4A*). South of that boundary, thinly bedded limestone predominates. At Aurora Mountain, Pardners Hill, and Lone Mountain, other areas characterized mainly by dolomite and dolomite breccia are labeled "dolomite" on the map. Other undesignated dolomite and dolomite breccia have been found north of Inerevuk and Cosmos Mountains, south of Cockscomb Ridge, and in the vicinity of Bornite. West of Aurora Mountain and Razorback Ridge, rocks assigned to the dolomitic limestone map unit consist mainly of crystalline limestone and marble.

Thinly bedded, fine-grained, weakly metamorphosed limestone is the most typical and abundant rock of this map unit. The limestone is especially well exposed near Shield Mountain, the east side of Inerevuk Mountain, and the southern side of Aurora Mountain. Beds commonly are only 2 or 3 mm thick, but in some places they are as much as 6 inches thick. The thinnest ones produce characteristic platy rubble that rattles under foot. This kind of rock consists mainly of sand-size grains of calcite, but also contains subordinate muscovite and quartz, minor pyrite, and ubiquitous dusty carbon, which Runnells (1963, p 121) identified as anthraxolite. Much of the rock is best described as weakly metamorphosed calcarenite. The main minerals commonly are elongate parallel to one another producing a conspicuous regional mineral lineation. Near the Shungnak River, more intense metamorphism has converted the limestone to white tremolite-bearing marble similar to that of unit Pzc exposed in the upper canyon.

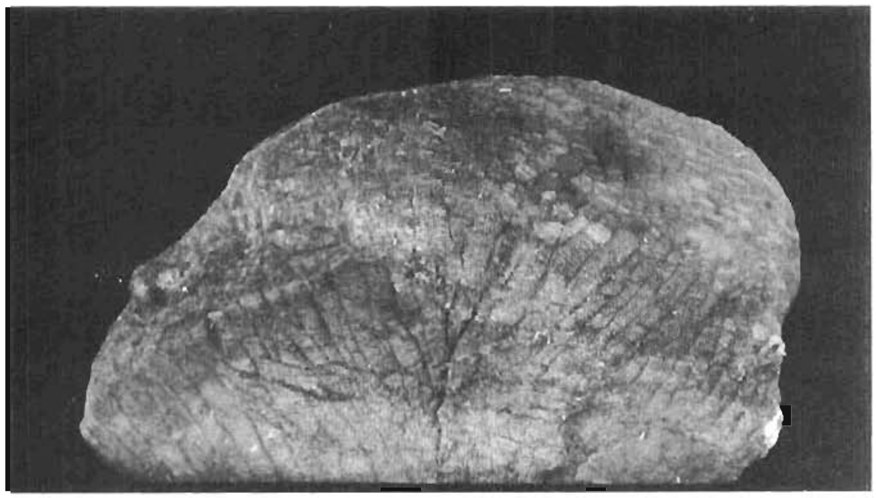
Dolomite and dolomite breccia form prominent reefs and bioherms within the main limestone. They commonly weather to rounded knobs and ridges covered by abundant coarse rubble with little or no vegetation (*cover photo and fig 5*). Much of the dolomitic rock is rusty light brown on weathered surfaces and is easily distinguished from adjacent gray limestone, even at distances of several miles. At Aurora Mountain, a small elliptical body of well bedded, nearly white dolomite underlies dark-gray phyllite and overlies a larger tabular body of rusty dolomite breccia, which overlies thinly bedded, light-gray limestone. The mountain undoubtedly received its name because of this conspicuous variation in color. Rusty dolomite breccia also is abundant at Lone Mountain and east of the two high-angle faults mapped at Pardners Hill. The typical dolomite breccia consists of angular to subangular fragments of fine-grained dolomite about 1 inch in diameter set in a matrix of similar fine-grained dolomite. Accessory minerals are iron and copper sulfides, iron oxides, and anthraxolite (Copper, under Economic geology). Magnetite and goethite are especially abundant at Lone Mountain, and account for its original name, Iron Mountain (Smith and Eakin, 1911, p 303). Near the eastern base of Pardners Hill, thinly bedded dolomite locally displays well developed ripple marks.

Another fragmental rock referred to informally as limestone breccia is associated with the dolomitic rocks, especially at and southeast of Bornite. This breccia consists of angular to subrounded fragments of fine-grained, dark-gray dolomite and calcite about 1 inch in diameter set in a matrix of fine-grained, light-gray calcite (Runnells, 1963, p 41-43). Somewhat similar rock characterized by nodules and lenses of dark-gray carbonate as much as 1 inch thick set in a matrix of thinly bedded light-gray limestone is well exposed near Riley Creek about 1½ miles northeast of Shield Mountain.

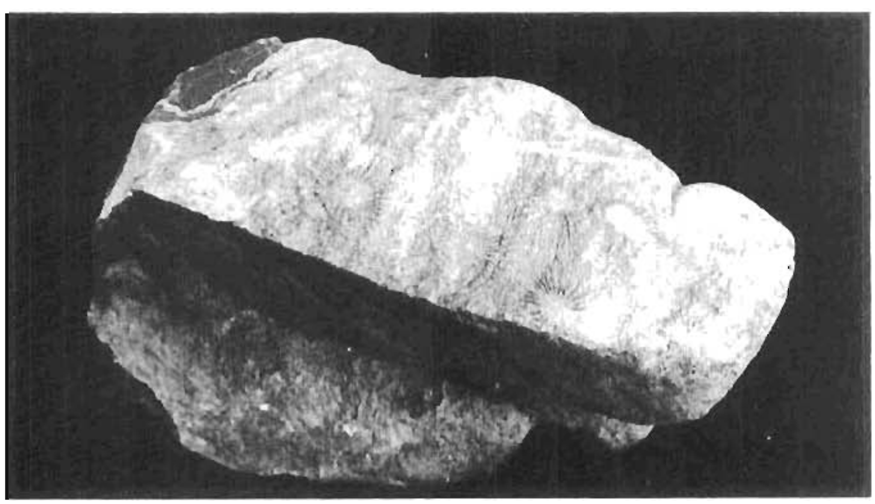
At several localities shown on the present geologic map (*fig 4A*), the dolomitic rocks contain moderately well preserved fossils. Coral was found in dolomitic strata east of Cosmos Mountain and in pelitic strata interbedded with carbonate rocks beneach dolomite breccia southeast of Bornite (*figs 7, 8*). Broken crinoids are locally abundant about 1 mile east of Cosmos Mountain. Tiny brachiopods and snails also have been found in dolomitic rocks exposed about 1½ miles east southeast of Bornite. At Lone Mountain, fragments in dolomite breccia contain broken corals. Fossils also have been found at Bornite in diamond-drill core studied by Chadwick (1960) and Runnells (1963). Patton, Miller, and Tailleur (1968) listed the main fossils found in this formation prior to mapping by the State. Fossils collected by the present writer in 1969 from the localities shown on figure 4A currently are being studied by members of the U. S. Geological Survey.

The presence of abundant calcarenite, corals, ripple-marked dolomite, and moderate amounts of dolomitic reef breccia in this formation indicate a shallow marine environment of deposition. The breccias are believed to have formed largely as a result of wave action on reefs and bioherms. Dolomitization is believed to have occurred at the time of reef building (Dolomitization and calcitization, under Copper in section concerning Economic geology).

Phyllite (Pzdp) -- Phyllite and tuffaceous phyllite grading into greenschist are interlayered with the main carbonate rocks in many places, but are exposed well enough to be mapped separately in only a few. At the northern face of Inerevuk Mountain, phyllite formerly interpreted as part of unit Pzp (*Fritts, 1969, p 10, fig 2*) now is known to be interbedded with carbonate strata characteristic of the main dolomitic limestone. A short stratigraphic section there was shown by Heide, Wright, and Rutledge (*1949, fig 4*). About 1 mile east southeast of Bornite, a unit of dark-gray phyllite containing stretched pebbles of quartz-sericite rock appears to be part of the main dolomitic limestone, although adjacent carbonate strata do not seem to be as strongly deformed. The possibility that this phyllite is equivalent to allochthonous phyllite of unit Pzup exposed at Cockscomb Ridge was considered in the field, but conclusive evidence for such a relationship was not found. Phyllite interbedded with dolomitic limestone is well exposed farther south, and similar interbedded phyllitic and carbonate strata have been penetrated by diamond-drill holes at Bornite (Copper, under Economic geology). Another small patch of phyllite overlying dolomitic limestone about 1 mile east of Cosmos Mountain may be part of this formation, but it appears to be at least partly in thrust contact with the dolomitic limestone. The possibility that the phyllite there is equivalent to unit Pzup exposed farther west also was considered, but field evidence is inconclusive. Unmapped tuffaceous and calcareous pelitic rocks, which Runnells (1963, p 33) referred to as albitic lime phyllite, is interbedded with dolomitic limestone penetrated by diamond-drill holes at Bornite. Other phyllite interpreted as part of this formation near Cosmos Creek was mapped by Heide, Wright, and Rutledge (*1949, fig 7*).

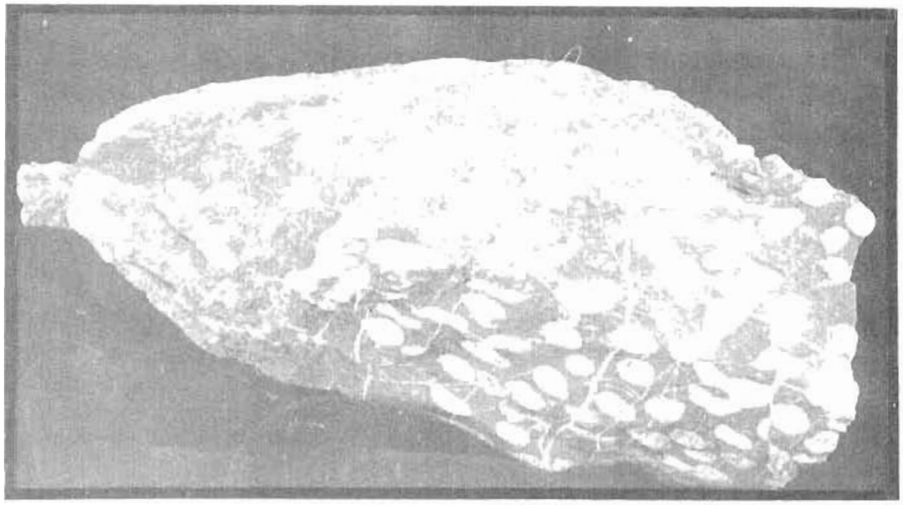


(A) *Favosites*, 4500 feet east of Cosmos Mountain summit.

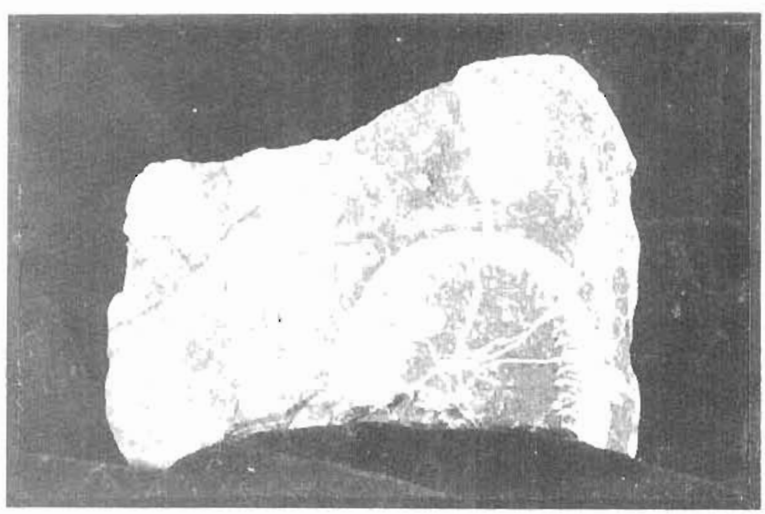


(B) *Billingsastraea*, 1050 feet southeast of Bornite shaft.

Figure 7. Fossils from dolomitic limestone, Pzd, Cosmos Hills. Approximately natural size.



(A) *Syringopora*, 1050 feet southeast of Bornite shaft.



(B) Rugose coral, probably *Siphonophrentis*, 1050 feet southeast of Bornite shaft.

Figure 8. Fossils from dolomitic limestone, Pzd, Cosmos Hills. Approximately natural size.

Near Wye Creek, dark-gray to black carbonaceous phyllite formerly assigned to unit Pzs (*Fritts, 1969, p 7, fig 2*) has been remapped as Pzdp, primarily because this phyllite now appears to be in the same thrust slice as the main dolomitic limestone. However, the limestone and phyllite apparently are separated by a high-angle fault near Dahl Creek. Thus the phyllite exposed at Wye Creek is in fault contact with all adjacent rocks, and its stratigraphic position is uncertain. This rock is only weakly metamorphosed. Along the west bank of Dahl Creek, it contains enough carbon to blacken the hands of those handling the rock, but it contains neither garnet nor albite porphyroblasts like those characteristic of unit Pzs farther east.

Greenstone and greenschist (Pzdg) -- Small bodies of greenstone and greenschist associated with rocks of the main dolomitic limestone were mapped separately at two localities southeast of Bornite and at another on the west side of Cosmos Mountain. At each locality, the greenstone and greenschist appear to be approximately parallel to bedding in adjacent strata. The northernmost greenstone southeast of Bornite is a medium-grained metagabbro composed mainly of plagioclase and augite partly altered to hornblende, but it also contains chlorite, epidote, carbonate, and accessory sphene. This rock appears to form a sill-like intrusive sheet more than 100 feet thick. The other greenstone mapped in that area is finer grained, distinctly schistose near its edges, and 20 to 30 feet thick. It also is interpreted as a metamorphosed intrusive mafic igneous rock. A much thinner unmapped greenschist layer in phyllite is exposed about 150 feet farther west. The greenschist mapped near Cosmos Mountain is about 30 feet thick and is believed to be a metamorphosed intrusive rock. Extremely thin greenschist layers interpreted as metatuff are known to be present in the main dolomitic limestone at Bornite. The greenstones described here, therefore, probably represent the intrusive equivalent of volcanic rocks deposited during or after the main episode of carbonate sedimentation.

Geologic age -- A Middle Devonian age has been assigned to the main dolomitic limestone on the basis of fossils collected from several localities in the Cosmos Hills prior to 1968 (Patton, Miller, and Tailleur, 1968). Preliminary examination of more fossils collected by the writer from these and other localities in the Cosmos Hills in 1969 tends to confirm the Middle Devonian age, although a detailed examination of those fossils had not been completed by May 1970 (J. T. Dutro, Jr., written communication). Runnells (1963, p 17; 1969, p 77) correlated the main dolomitic limestone of the Cosmos Hills with the Skajit Limestone of the Brooks Range. Greenstone, which represents metamorphosed igneous rock intruded into the dolomitic limestone, cannot be older than Middle Devonian or younger than Early Cretaceous (Metamorphism).

Upper phyllite and related rocks (Pzup, Pzud, Pzug)

A thrust slice composed primarily of phyllite, with subordinate greenstone and carbonate rocks, overlies the main dolomitic limestone in the western part of the Cosmos Hills. This phyllite can be traced from the northern face of Shungnak Mountain around the western end of the main window to Cockscomb Ridge and Jay Creek. It may continue across Ruby Creek pinching out eastward, as suggested on figure 4A, but this rock is not exposed east of Jay Creek. The interpretation shown on the map, therefore, is speculative. Phyllite that caps Aurora Mountain apparently is a remnant of this thrust slice, as suggested on cross sections A and C (*fig 4B*).

Phyllite (Pzup) -- The predominant phyllite is medium dark gray and lithologically similar to other weakly metamorphosed pelitic rocks described above. It consists primarily of fine-grained muscovite and quartz, and contains neither garnet nor albite porphyroblasts. The metamorphic grade of the rock, therefore, is much lower than that of the marble over which it has been thrust near the Shungnak River.

Limestone and dolomite (Pzud) -- Thinly bedded limestone about 100 feet thick crops out in a prominent cliff near the head of Serpentine Creek, but cannot be traced far. Similarly, dolomitic limestone rubble is abundant on a ridge about 1 mile south of the thinly bedded limestone, but appears to be isolated from that rock. Both of these carbonate rocks are near another major overthrust fault and may be offset by unrecognized faults. However, the rocks are interpreted as units interbedded with the main phyllite, Pzup. A poorly preserved Favosites was found in dolomitic rock south of Serpentine Creek in 1969.

Greenstone (Pzug) -- Greenstone similar to that of unit Pzdg apparently intrudes rocks in the lower part of unit Pzud near Alder and Fire Creeks. However, the greenstone is exposed mainly as aggregates of coarse rubble. Greenschist is not abundant in unit Pzup.

Geologic age -- The age of the phyllite and carbonate rocks is believed to be Devonian, mainly because they are lithologically similar to the well dated Middle Devonian strata of the area and contain similar fossils. However, their exact stratigraphic position is uncertain because of overthrust faulting. The age of the greenstone in this thrust slice is believed to be comparable to that of unit Pzdg.

Upper carbonates (Pzuc)

Bedded carbonate rocks lithologically similar to those described above crop out in a few places west of Moose Mountain and north of Cockscomb Ridge, but are generally poorly exposed. Near Cockscomb Ridge, they probably are interbedded with pelitic rocks (I. L. Tailleur, unpublished map). These rocks have not been carefully studied by the present writer, but most likely are part of the main thrust-faulted stratigraphic sequence of Devonian age.

Metabasalt and related rocks (Pzp, Pzv, Pza, Pzl)

A thick formation of weakly metamorphosed volcanic and sedimentary rocks is exposed in a belt as much as ½ mile wide and 14 miles long along the southern and eastern sides of the Cosmos Hills, and in a belt about 2 miles wide and 5 miles long northeast of Bornite. These rocks have been thrust over the main dolomitic limestone (Pzd) and other strata described above. In this area, the formation includes a lower phyllitic member (Pzp) and a predominant upper metavolcanic member (Pzv), which contains lenses of limestone (Pzl) and agglomerate (Pza). Metavolcanic rocks similar to those of the upper member crop out on both sides of Kollioksak Lake and extend eastward for many miles through the Angayucham Mountains (Patton, Miller, and Tailleur, 1968). The total thickness of this formation is uncertain. It is at least 1500 feet near Ferguson Peak in the Cosmos Hills, but probably is several thousand feet in the Angayucham Mountains.

Lower phyllitic member (Pzp) -- The lower member consists mainly of interbedded phyllite, metagraywacke, and metatuff. Rocks of this member are exposed intermittently only from Inerevuk Mountain to Dahl Creek. A westward extension across Wesley Creek inferred in previous reports (Fritts, 1969; Patton, Miller, and Tailleur, 1968) was not confirmed in the course of detailed mapping in 1969. Although field relations along the southern side of the Cosmos Hills suggest the possibility that units Pzp and Pzup are equivalent, such a relationship is not evident near Bornite. The two predominantly pelitic units appear to be confined to separate thrust sheets. West of Dahl Creek, some of the rocks of this map unit are characterized by intimately interlayered black phyllite and greenish-gray metatuff beds a few millimeters thick, and the rocks are indistinguishable from interbedded phyllite and metatuff found in unit Pzv at Stout Mountain. Intimately interbedded rocks like these are not characteristic of unit Pzup. The metatuff of unit Pzp consists mainly of chlorite, actinolite, and epidote, and the phyllite consists largely of muscovite and quartz, with abundant accessory carbon.

Upper metavolcanic member (Pzv) -- The upper member consists mainly of metabasalt and metatuff, but also contains moderate amounts of interbedded phyllite and metagraywacke as well as small lenses of crystalline limestone. Massive, locally amygdaloidal metabasalt is well exposed near Moose Mountain, the heads of California and Canyon Creeks, and a low knoll about 2¼ miles east southeast of Camp 3. This rock contains abundant plagioclase, epidote, and chlorite, and exhibits a relict diabasic texture in thin section. It contains numerous amygdules 1 to 3 mm in diameter filled with chlorite. At Moose Mountain, it displays moderately well preserved pillow structures 1 to 2 feet in diameter. In several places, it displays fragmental textures typical of mafic lava flows. Well-bedded metatuff composed of actinolite, epidote, chlorite, and albite is abundant throughout this member, especially along the southern side of the Cosmos Hills. It is well exposed on Stout Mountain, and is interbedded with phyllite composed mainly of muscovite, quartz, albite, and probable very fine-grained brown biotite. Alternating beds of phyllite and metatuff there are as thin as 1 or 2 mm, but many are much thicker. Rubble on the south side of Moose Mountain includes phyllite, metatuff, metagraywacke, and impure quartzite. Accessory minerals in the metavolcanic rocks are sphene, rutile, hematite, and magnetite. At a prominent knob near the center of the SW¼ sec. 22, T. 18 N., R. 10 E., the metavolcanic rocks contain enough microscopic magnetite to deflect a compass needle.

Agglomerate (Pza) -- Fragmental rock interpreted here as metamorphosed agglomerate or intraformational volcanic conglomerate crops out near the center of sec. 12, T. 18 N., R. 10 E. This rock is characterized by an extremely rough weathered surface on which numerous unstretched subangular fragments of metabasalt as much as 10 inches in diameter stand out above the surrounding fine-grained matrix. The fragments are lithologically similar to underlying amygdaloidal metabasalt. The matrix is metatuff or metasedimentary rock derived from metavolcanic rock. The agglomerate or conglomerate is overlain by greenschist in the southern part of sec. 12, and appears to be part of a conformable sequence of predominantly metavolcanic strata (Pzv). Fragmental metavolcanic rock also is associated with metabasalt in and near the NE¼ sec. 1, T. 18 N., R. 10 E., but is not differentiated on the geologic map.

Limestone (Pzl) -- Thinly bedded limestone is interlayered with the metavolcanic strata (Pzv) at Moose Mountain and in many places along the southern side of the Cosmos Hills. The limestone forms lenses from less than 1 foot to as much as 60 feet thick. In general, these lenses and bedding within them are parallel to bedding and foliation in the adjacent metavolcanic rocks. However, at Moose Mountain, bedding in one such limestone is markedly oblique to the outline of the lens mapped, indicating strong internal deformation and probable shearing along the boundaries of the lens. This is the thickest such lens in the map area, but another large one approximately 30 feet thick is well exposed at Stout Mountain. On the south side of that mountain, the limestone contains a layer of greenish-gray metatuff approximately 20 feet long and as much as 1½ feet thick, which parallels bedding in the limestone. The field relations indicate contemporaneous deposition of limestone and tuff.

The limestone (Pzl) is at least partly bioclastic, and some of it strongly resembles calcarenite characteristic of the main dolomitic limestone (Pzd). At Stout Mountain, limestone adjacent to the metatuff lens described above consists mainly of calcite, but contains numerous microscopic grains of clastic quartz and macroscopic grains of dark-gray clastic calcite as much as 2 mm in diameter. In thin section, some of the dark-gray clastic grains were recognized as distinct fragments of crinoids replaced by calcite. Much larger fragments of crinoids were found in similar limestone float in the southeast corner of sec. 22, T. 18 N., R. 10 E. The float there apparently was derived from a small body of bioclastic limestone exposed about 1000 feet west northwest of the summit of Ferguson Peak. Fragments of crinoid stems from the Ferguson Peak locality are as much as ¼ inch in diameter and ½ inch long. These crinoid-bearing limestones are indistinguishable from crinoid-bearing limestone found within the main dolomitic limestone (Pzd) about 1 mile east of Cosmos Mountain. Three kinds of conodont (Hindeodella sp., Ligonodina? sp., and Ozarkodina sp.) also have been identified in samples of the crinoid-bearing limestone collected by the writer at Ferguson Peak (J. W. Huddle, written communication, June 1969). The conodonts, however, are rather scarce in the specimens of this rock studied so far.

Geologic age -- The age of this formation is reported here as Middle Devonian(?) primarily on the basis of paleontological evidence and lithological similarity between limestones of units Pzl and Pzd. Previous estimates of the age of the predominantly metavolcanic formation (Pzv) have ranged from Jurassic(?) (Patton, Miller, and Tailleur, 1968) to possible Devonian (Fritts, 1969, p 12). The latter age was based partly on the presence of crinoids in unit Pzl at Stout Mountain and Ferguson Peak, and partly on the presence of phaceloids (rugose corals) of possible Devonian age in similar limestone interlayered with the main metavolcanic formation near the Mauneluk River about 11 miles east of Kollioksak Lake. The presence of locally abundant crinoids within the main dolomitic limestone (Pzd) of Middle Devonian age was not known until July 1969, but the crinoid-bearing rocks in both units (Pzd and Pzl) are so similar lithologically that similarity in geologic age also seems likely. The conodonts mentioned above are characteristic of rocks ranging in age from Ordovician to Triassic, and the ones collected from the Cosmos Hills could indeed be Middle Devonian in age (J. W. Huddle, written communication, June 1969). Thus the evidence presently available favors a Middle Devonian(?) rather than Jurassic(?) age.

Cretaceous Rocks

Metaconglomerate and related rocks (Ks, Kp, Kb)

The highest stratigraphic formation in the Cosmos Hills consists of a predominant conglomeratic sandstone and slate unit of probable continental origin (Ks), with subordinate phyllite (Kp) and metabasalt (Kb). These rocks have been thrust over underlying Devonian strata. In the lower part of the main map unit, especially within 400 or 500 feet of the underlying fault, the Cretaceous rocks have undergone pervasive shearing and low-grade dynamic or dynamo-thermal metamorphism which distinguish them from the underlying Devonian strata. Other distinguishing features in this area include an abundance of coarse clastic material and an apparent lack of limestone. The formation underlies more than 40 square miles in the western, southern, and eastern parts of the Cosmos Hills, and is characteristic of rocks in the northern part of the Kobuk trough. The thickness of the Cretaceous strata in the Cosmos Hills is uncertain because of faulting, but probably is several thousand feet. In the Selawik quadrangle, at localities about 100 miles west of Kobuk, the thickness of equivalent rocks is at least 3000 feet and may be as much as 7500 feet, if underlying conglomerate of marine origin is included (Patton and Miller, 1968).

Conglomeratic sandstone and slate (Ks) -- The conglomeratic sandstone and slate unit is well exposed on mountain summits and flanks along the entire western, southern, and eastern rims of the Cosmos Hills window, but severe frost action has reduced many outcrops to concentrations of slabby boulders 1-20 feet in diameter. The map unit consists of interbedded metaconglomerate, metasandstone, metagraywacke, and phyllite or slate. Beds 1-6 feet thick are common. Fine-grained rocks exhibiting typical slaty cleavage were observed mainly south of an east-trending fault south of Ferguson Peak, but also are present in the western part of the area. Phyllite, metagraywacke, and metasandstone are widespread, but are especially abundant east of the Kogoluktuk River and west of the Shungnak River. Metaconglomerate also is widespread, but is coarsest and most abundant along the southern flank of the Cosmos Hills, especially in the vicinity of Dahl and Wesley Creeks. Common minerals in all of these rocks include quartz, muscovite, chlorite, biotite, and feldspar. Most cobbles and pebbles in the metaconglomerate are white quartz, but pebbles of metagraywacke, schist, greenschist, chert, and granitic gneiss presumably derived from the ancestral Brooks Range also are present. No limestone pebbles or cobbles were noticed in the course of mapping by the writer. The largest clastic fragment found in the metaconglomerate was a quartz boulder 6 x 8 x 15 inches near Wesley Creek. Alignment of stretched cobbles, pebbles, and grains in these sheared rocks gives them a conspicuous lineation, which commonly trends northeast. Recognition of this feature is helpful in mapping, because it enables the mapper to distinguish between outcrops and frost-heaved debris.

Highly sheared metaconglomerate characterized by extremely stretched and flattened pebbles and cobbles of greenschist is well exposed (1) within 100 feet of the uppermost overthrust fault mapped on the northwest side of Cosmos Mountain, (2) at the summit of Ferguson Peak, (3) near the divide between the heads of California and Canyon Creeks, and (4) on a north-trending spur on the west side of Kollioksak Lake. The matrix of these rocks commonly is grayish to purplish red, making them quite distinctive in the field. In the southeastern part of the Cosmos Hills, this kind of rock formerly was mapped separately (*Fritts, 1969, fig 2*) in the belief that it might represent part of a lowermost member of the main Cretaceous formation described by Patton, Miller, and Tailleur (1968). However, similar red conglomerate characterized by fragments of volcanic rock now is known to be interbedded with the typical quartz-pebble conglomerate in the Angayucham Mountains. In the Cosmos Hills, the conglomerate containing greenschist fragments apparently was merely more easily deformed and altered close to the uppermost overthrust fault at the time of emplacement of intrusive serpentinite (see Serpentinite and serpentinization). At Cosmos Mountain within one foot of serpentinite intruded along that fault, numerous pebbles in this kind of conglomerate consist mainly of antigorite, which strongly resembles antigorite characteristic of the adjacent serpentinized intrusive ultramafic rock. The field relations suggest that the conglomerate also has been serpentinized to a minor degree, or at least chloritized, during emplacement and alteration of the intrusive rock.

Phyllite (Kp) -- Phyllite was mapped separately east of Wesley Creek primarily to emphasize the northeast trend of bedding where well foliated metaconglomerate predominates. Bedding and foliation there are parallel. In thin section, the phyllite is composed mainly of muscovite, quartz, and probable feldspar, but also contains scattered porphyroblasts of chlorite as much as 0.2 mm in diameter, which are oblique to foliation and bedding. This kind of porphyroblast is typical of pelitic rocks observed by the writer in New England, which have undergone metamorphism in the lower greenschist facies. Carbon also is present, but is less abundant than carbon in phyllite of Paleozoic age exposed near Dahl Creek.

Metabasalt (Kb) -- Fine- to medium-grained, weakly metamorphosed, mafic volcanic rocks form two large generalized map units underlying 1 or 2 square miles each east of the Shungnak River and at least two smaller bodies near Shungnak and Bismark Mountains. The smallest unit near Shungnak Mountain is only about 20 feet thick and appears to be parallel to bedding in the adjacent clastic rocks. Mafic rocks showing good diabasic texture are characteristic of these units, but porphyritic rocks containing altered plagioclase phenocrysts several millimeters in diameter were found in rubble on the northern side of Shungnak Mountain. The rocks with diabasic texture range from basalt to gabbro in appearance, and fine-grained locally amygdaloidal basalt is typical at Shungnak Mountain. The basalt is brown on weathered surfaces and is easily recognized from the air. The rock consists mainly of plagioclase and augite, with small amounts of chlorite and magnetite. Chlorite commonly forms amygdules 1-3 mm in diameter. Amygdaloidal rocks with good diabasic texture are believed to be only slightly altered extrusive basalt. Coarse nonamygdaloidal rocks exposed near the Shungnak River may be the intrusive equivalent of the basalt. Although slightly altered, these rocks all appear to be much less metamorphosed than the greenschists and greenstones of Devonian age found in this area, and they do not contain interlayered limestone.

Geologic age -- A Late Cretaceous age was assigned to the metaconglomerate and related rocks of the Cosmos Hills by Patton, Miller, and Tailleur (1968) on the basis of correlation with similar rocks exposed in the Baird Mountains and Selawik quadrangles west of Kobuk. The conglomeratic strata in those quadrangles contain tuffaceous beds dated by potassium-argon methods. The authors also reported that some of the strata exposed in the eastern part of the Cosmos Hills resemble igneous pebble-cobble conglomerate like that interbedded with fossiliferous mudstone and graywacke of probable Early Cretaceous age in the Selawik quadrangle (Patton and Miller, 1968). The age of this formation, therefore, is reported here as Early to Late Cretaceous. Runnells (1963, p 18, 19) correlated these rocks with strata of the Bergman and Koyukuk Groups.

INTRUSIVE ROCKS

Cretaceous Rocks

Granite (Kg)

Distribution and size -- Gneissic granite forms a pluton as much as 1 3/4 miles in diameter near the Kogoluktuk River. This rock forms the core of a dome, and is surrounded by the most highly metamorphosed strata in the map area. The granite is well exposed along the river and on ridges near Radio and Lynx Creeks. Schist crops out in several places along the northern side of the pluton, providing good control for placement of the granite-schist contact there. Along the southern side, however, outcrops of granite and schist are as much as 1 mile apart. Thus the nearly circular outline of the pluton shown on the map is generalized and merely indicates the minimum area underlain by granite. Small unmapped bodies of pegmatitic to gneissic rock as much as 6 feet thick, which are believed to be related to the granite, were found near marble about 1½ miles east of the pluton and in schist near Glacier Creek a comparable distance to the west. No other granite bedrock was seen by the writer in the Cosmos Hills.

Garnetiferous greenstones and schists presumably metamorphosed at the time of granite emplacement are most abundant in an irregular belt at least 3 miles wide and 6 miles long, which trends approximately N 30 W from California Creek near Crescent Ridge to and beyond Black Rock Ridge. This belt includes the small pluton of intrusive granite, which is slightly elongate about parallel to the N 30 W trend. The field evidence suggests that the granite may extend beneath this belt of garnetiferous rock. The presence of schist and marble near the Shungnak River also suggests that granite was close to those rocks at some time in the past, but discordances in bedding there suggest that the rocks are complexly faulted rather than domed. In the opinion of the writer, granite very likely was associated with metamorphism of rocks now exposed near that river but was separated from them or covered by other strata during subsequent overthrust faulting.

Lithology -- The granite consists mainly of albite, microcline, quartz, and muscovite. Biotite is much less abundant. The microcline forms numerous crystalloblasts 1/2 to 3/4 inches long. Some are smeared out parallel to well developed foliation. Deformation of these crystals presumably occurred during a late stage of the emplacement and related metamorphism. Accessory minerals are sphene, carbonate, and zircon. Garnets 1-5 mm in diameter are present in some outcrops adjacent to schist. The granite is cut by minor aplite dikes and sills, which are oblique and parallel to foliation, respectively. Well developed jointing is characteristic.

Lithologies at the northernmost outcrops of the granite on the Kogoluktuk River clearly indicate that this rock intrudes the adjacent schist (Pzs). The granite there contains inclusions of garnetiferous muscovite schist similar to the host rock. The granite also contains distinct muscovite- and garnet-rich layers, which represent partly assimilated schist. Some layers contain stubby crystals as much as 3 mm in diameter, which resemble the albite porphyroblasts characteristic of the intruded schist (Pzs). Small nearly round albite crystals also are characteristic of granite gneiss found near marble east of Lynx Creek.

Geologic age -- An Early Cretaceous age was assigned to this granite by Patton, Miller, and Tailleur (1968) on the basis of potassium-argon dating of hornblende collected from a small inclusion of country rock found in soda aplite associated with the granite (W. W. Patton, Jr., oral communication, February 1970). Laboratory data suggest an apparent age of 121 ± 3.8 million years for the hornblende, which is believed to have formed, or at least recrystallized, during metamorphism directly related to emplacement of the granite. The reported figure, therefore, is a minimum estimate of the age of the granite, which is compatible with field evidence. Field relations indicate that the granite cannot be older than Middle Devonian, because it intruded, deformed, and metamorphosed a stratigraphic sequence that includes rocks of Middle Devonian age. The granite presumably is not younger than Early Cretaceous, because it is part of a folded, faulted, and metamorphosed sequence over which strata of Early to Late Cretaceous age have been thrust. Those strata were derived from the ancestral Brooks Range, which formed as a result of orogeny involving granite emplacement and overthrust faulting (Structure and geologic history).

Quartz veins

Quartz veins, lenses, and pods believed to be related mainly to metamorphism and granite emplacement intrude metamorphosed Devonian strata. These veins range in thickness from less and 1 inch to more than 4 feet. In phyllite, the quartz tends to be massive, white, approximately parallel to bedding and foliation, and may contain feldspar, muscovite, and pyrite. Massive quartz float is especially abundant on a ridge of phyllite about ½ mile east southeast of the summit of Shield Mountain, and reportedly contains gold (Gold, under Economic geology). In carbonate rocks, similar veins tend to be vuggy, oblique to bedding, and may contain nearly clear euhedral quartz crystals as much as 2 inches in diameter, in addition to minor carbonate. Large quartz crystals were observed mainly in veins that cut units Pzc near the head of Wesley Creek and Pzd near the adit at Pardners Hill. Veins in that area also contain copper sulfides and copper carbonates, which are believed to be younger than the main metamorphism (Copper, under Economic geology).

Small quartz veins also cut Late Cretaceous strata and obviously cannot be related to Early Cretaceous metamorphism. It is possible that some of the veins cutting Devonian strata, therefore, may be considerably younger than the granite (Kg). Veins are discussed further under the headings Serpentinite and Economic geology.

Tertiary(?) Rocks

Serpentinite (Ts)

Size, shape, and distribution -- Serpentinite in the Cosmos Hills forms numerous tabular intrusive bodies parallel or nearly parallel to planar features such as bedding, foliation, and overthrust faults. These bodies are from 100 feet to 5 miles long but only about 10 to 400 feet thick. They are good examples of the alpine-type ultramafic rocks that are derived from the earth's mantle and altered during emplacement in intensely deformed orogenic belts (Benson, 1926, p 6). In this area, serpentinite is most abundant along the southern and western sides of the Cosmos Hills window, where sheets of this rock several miles long but less than 100 feet thick have been emplaced along a major overthrust fault beneath strata of Early to Late Cretaceous age. The serpentinite there is highly sheared, and the common thickness of 10 to 50 feet tends to be exaggerated by severe slumping on steep slopes. The longest or broadest sheet is exposed near Shungnak and Cosmos Mountains. The thickest one is about 1 mile northwest of Ferguson Peak. In a few places such as Asbestos Mountain and Knob Hill, tabular, gently inclined serpentinite bodies have been emplaced near the axis of a major anticline within the window, but this rock is rare along the northern flank of the main structure east of the Shungnak River. Typical sill-like and gently inclined dike-like bodies of serpentinite are shown on geologic cross sections A, C through H, and J (*fig 4B*). The composition and distribution of this rock suggest that its source was at great depth somewhere south or southwest of the Cosmos Hills, perhaps beneath the western end of the Kobuk trough (*fig 1*).

The large apparently isolated body of serpentinite at Asbestos Mountain is one of the highest, most conspicuous, and most controversial in the map area. It can be seen easily from the Dahl Creek air strip. The mapped outline of this body is mainly the outline of an area containing intermittent outcrops and abundant, tough, angular, frost-heaved serpentinite boulders as much as 10 feet in diameter, which undoubtedly have not moved far. This body formerly was interpreted as part of a C-shape stock extending from the mountain summit southward to the confluence of Dahl and Stockley Creeks (Heide, Wright and Rutledge, 1949, fig 9, after Coats, 1943, fig 1). However, no indisputable evidence was found during the recent mapping to indicate that the small bodies of serpentinite exposed there presently are connected to one another or to the large body at the mountain summit. Furthermore, the magnetic expression of the main serpentinite at Asbestos Mountain suggests a "sill-like form" (Chadwick, 1960, p 5). When viewed from the south, the mountain resembles a mesa capped by serpentinite. The cap is interpreted here as a gently inclined dike 150 to 200 feet thick oblique to the contact between formations Pzs and Pzg, as shown on cross sections A and C (*fig 4B*). Section G also suggests that this dike may have extended southward to the confluence of Dahl and Stockley Creeks prior to erosion responsible for the present topography, but such an extension is not required by the available field evidence. The point that deserves the most emphasis here is that field relations in the vicinity of Asbestos Mountain do not indicate a great lateral extent or vertical thickness of serpentinite at that locality.

Lithology -- The ultramafic rocks of the Cosmos Hills have undergone shearing and brecciation as well as complete recrystallization to serpentinite and related minerals. Shearing is most intense in the serpentinite found along the uppermost overthrust fault near Inerevuk, Cosmos, Shungnak, and Bismark Mountains. Many "outcrops" there, especially west of Cosmos Creek, consist almost entirely of light-greenish-gray to dark-green serpentinite chips ¼ to 2 inches in diameter characterized by smooth slick surfaces. These exposures also contain scattered nodules and blocks of relatively unsheared serpentinite from a few inches to 10 feet in diameter. More massive outcrops in the same belt exhibit brecciated serpentinite containing fragments from ¼ to 6 inches in diameter. Such exposures also show lenses of relatively unsheared serpentinite as much as 5 feet thick and 15 feet long, which commonly parallel foliation. The perimeters of some of the intrusive bodies appear to be more foliated than the central parts, and the foliation tends to be roughly parallel to their boundaries. However, a contact between the intrusive rock and the overlying conglomeratic host rock is exposed for approximately 150 feet on the northwest side of Cosmos Mountain, and the serpentinite there is not as strongly sheared as rock in other parts of the same belt. Serpentinite farther from major faults tends to exhibit a higher proportion of relatively unfoliated or unsheared material, but individual outcrops commonly show minor shear zones and slickensided joints along which movement undoubtedly has occurred. In excavations at Asbestos Mountain, Heide, Wright and Rutledge (1949, p 12) found two main sets of nearly vertical fractures striking northeast and northwest and a third set nearly horizontal. Blocky rubble usually is abundant near outcrops containing such fractures.

Where least sheared, the typical serpentinite is composed largely of very fine-grained antigorite. Crystals of this mineral commonly are less than 0.2 mm in diameter. One thin section of serpentinite collected near Wesley Creek exhibits a texture with numerous small curved fractures suggesting that the rock formed by complete alteration of dunite or olivine-rich peridotite. No olivine or pyroxene, however, has been identified by the writer in serpentinite from the Cosmos Hills. A few samples from the same locality resemble porphyritic rocks, because they contain antigorite crystals as much as 3 mm in diameter set in a matrix of very fine-grained antigorite. Porphyritic-looking serpentinite also was found south of Stockley Creek and north of Tent Creek, where the rock contains numerous anhedral carbonate crystals as much as 5 mm in diameter scattered through a matrix of very fine-grained antigorite. The carbonate, however, appears to be replacing antitorite. In all of the serpentinite, fine-grained disseminated magnetite is a common accessory mineral. It is abundant enough in some hand samples to deflect a compass needle, and is plentiful enough in outcrops to make magnetic bearings unreliable. Other accessory minerals are pyrite and chromite. Weathered surfaces on the typical massive serpentinite commonly are rusty brown due to the presence of iron. A few are nearly black suggesting the presence of manganese. The brown surfaces are quite distinctive and can be recognized from as far as 5 miles away.

Several of the more interesting or unusual minerals and elements found in the map area are associated with the serpentinite. Many outcrops exhibit tiny veinlets of tremolite and (or) chrysotile 1-2 mm wide. Although large ones are uncommon, veins of asbestiform tremolite and chrysotile as much as 6 inches wide have been found at Asbestos Mountain (Heide, Wright, and Rutledge, 1949, p 11, 12). Most of the asbestos fibers are less than 3 inches long, but rate 18- to 20-inch fibers have been reported from that locality. Nemalite, an iron-bearing fibrous variety of brucite, has been found at Bismark Mountain (idem., fig 5A, p 10, 11). Fibrous serpentine crystals as much as 8 inches long were seen by the writer southeast of the summit of Knob Hill and in sec. 10 west of Dahl Creek. Near the head of Harry Creek and north of Tent Creek, float derived from small bodies of serpentinite includes talc and dolomite crystals as much as 1 inch long and coarse tremolite-actinolite rock, which contains small lenses of fine-grained, vivid green, chromium-bearing muscovite. The nephrite variety of jade has been found at Asbestos Mountain (Coats, 1943). Green boulders currently recovered from Dahl Creek placers for sale as jade undoubtedly were derived from the serpentinite. Chromite masses as much as 1 foot in diameter also have been recovered from those placers (Smith and Eakin, 1911, p 294) and are believed to have been derived from the serpentinite. Rhodochrosite possibly derived from this rock was recovered from the Stewart claim on Dahl Creek northeast of Camp 1 in 1969. Minor nickel has been identified in antigorite associated with chrysotile near Stockley Creek (U. S. Bur. Mines, 1944, p 5; Anderson, 1945, p 7), but is not plentiful enough to constitute a potential source of nickel under present economic conditions.

Relationship to ultramafic rocks of the Jade Mountains -- The serpentinite of the Cosmos Hills is believed to be genetically related and equivalent to partially serpentinized peridotite and dunite found along the southern side of the Jade Mountains (*fig 2*). The serpentinized peridotite and dunite there constitute the largest and westernmost body of ultramafic rock exposed along the north edge of the Kobuk trough. Thick units of carbonate and metavolcanic strata of pre-Cretaceous age and conglomeratic strata of Cretaceous age mapped in the Jade Mountains by Patton, Miller, and Tailleur (1968) are believed to be equivalent to rocks of units Pzd, Pzv, and Ks, respectively, of the Cosmos Hills. A thin unit of pelitic rocks of pre-Cretaceous age between the metavolcanic and carbonate strata in the Jade Mountains occupies a position comparable to that of unit Pzup or Pzp of the Cosmos Hills. The authors showed that the main metavolcanic unit in the Jade Mountains dips gently toward the south-southwest. On the basis of their mapping and aerial reconnaissance by the writer, a generalized geologic cross section (*fig 9*) has been constructed to show that the serpentinized ultramafic rock exposed along the southern side of the Jade Mountains can be interpreted as a tabular sheet as much as 800 feet thick and more than 8 miles long, which dips southwestward as much as 15°. Cretaceous strata exposed at the southeastern end of the Jade Mountains are believed to extend westward beneath a broad area covered by surficial materials immediately south of that ultramafic sheet. The general geologic setting of the main bedrock units in the Jade Mountains, therefore, appears to be grossly similar to that of bedrock units on the southern side of the Cosmos Hills window, with serpentinized intrusive ultramafic rock emplaced along or near a major overthrust fault now believed to underlie Cretaceous strata in both areas.

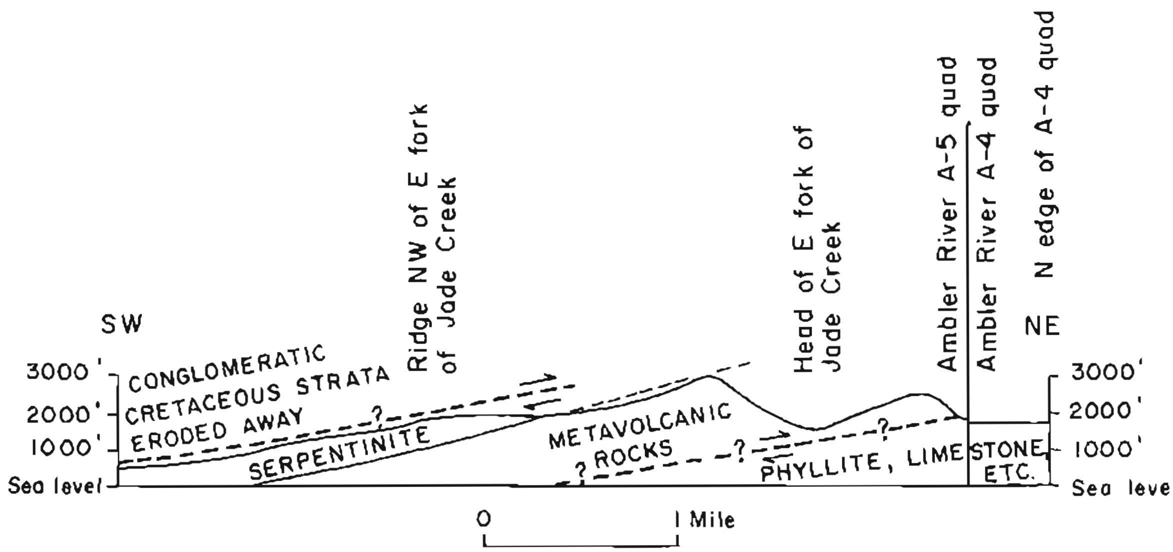


Figure 9. Generalized geologic cross section through part of the Jade Mts., northeastern corner of the Ambler River A-5 quadrangle, Alaska. Section strikes N 39° E through a prominent ridge between two main forks of Jade Creek.

Serpentinization -- Serpentinization of dunite and peridotite is believed to occur in the presence of water at temperatures far below those at which magmas of appropriate ultramafic composition should crystallize. O'Hara (in Wyllie, 1967, fig 1.2, p 10) has shown that dunite (mainly olivine) should crystallize at about 1900° C. and harzburgite (mainly olivine and orthopyroxene) at about 1600° C., whereas the temperature of normal basalt at volcanic vents is about 1100° to 1200° C. He also reviewed evidence indicating that alpine-type peridotites probably have reached equilibrium under widely varying geologic conditions involving pressures from 0 to 20 kilobars and temperatures from 400° to 1200° C. (idem p 403). However, the lack of wide metamorphic aureoles around many dunite and peridotite bodies has led to the general belief that they are tectonically transported from the mantle and are squeezed into the earth's crust as warm crystal mushes or nearly solid masses rather than flowing as extremely hot molten material. Upon contact with water, presumably present in the invaded host rock, serpentinization occurs along the edges of large intrusive masses or throughout small ones under the right conditions, thereby lubricating the masses and facilitating further movement. Serpentinization is believed to occur within the approximate ranges of 1 to 12 kilobars and 250° to 500° C., with temperatures most likely 400° to 500° (idem fig 1.4, p 10; fig 12.6, p 402). Deer, Howie, and Zussman (1966, fig 79, p 229) suggest that serpentine probably can exist to depths of about 7 miles.

Field evidence in the Cosmos Hills suggests moderate temperature and pressure at the time of serpentinization there, most likely at a depth of 2 or 3 miles. Along the southern side of this highland, Cretaceous strata within several hundred feet of the overthrust fault that underlies them have been subjected to metamorphism of the lower greenschist facies during the latest episode of overthrust faulting (Phyllite, Kp, and Metamorphism). Along the serpentinite-conglomerate contact exposed on the northwest side of Cosmos Mountain, conglomerate within about 1 foot of the intrusive serpentinite is highly altered. Thin sections of the altered rock show that lithic fragments and matrix both have been completely replaced by antigorite. Numerous tiny garnets less than 0.1 mm in diameter have formed along the rims of such fragments and in the adjacent matrix. The garnet has been identified by X-ray diffraction as largely grossularite or perhaps a hydrated variety of that mineral. Deer, Howie, and Zussman (1966, p 25) report that anhydrous grossular has been produced in the laboratory at 500° C., and probably is stable with water to 400° C. In contrast, the writer has mapped contacts in Connecticut where the emplacement of an intrusive diabase sheet of Triassic age 100 to 700 feet thick and 18 miles long has merely discolored conglomeratic arkose and siltstone of the Newark Series for about 100 feet above the diabase without large-scale recrystallization. At the time of emplacement, the diabase was overlain by clastic sediments having a thickness of 1½ to 2 miles or more.

Serpentinization of the ultramafic rock exposed in the Jade Mountains apparently has been incomplete in the central part of the intrusive sheet exposed there (*fig 9*) but rather thorough along its edges. Heide, Wright, and Rutledge (1949, p 13, 14) reported that serpentinization has been least thorough in some of the lowermost outcrops along Jade Creek on the southwestern side of the Jade Mountains and in downfaulted ultramafic rock mapped by Patton, Miller, and Tailleur (1968) at the southeastern end of that highland. The lowermost outcrops along Jade Creek, for example, reportedly expose rocks composed largely of pyroxene and olivine, which probably are characteristic of the innermost part of the intrusive sheet. The degree of serpentinization of the rock increases northeastward toward what now is interpreted as the base of the sheet. Serpentinite also predominates along the crest of the ridge between the East and West Forks of Jade Creek, where the upper part of the sheet apparently is exposed (*fig 9*). The incompleteness of serpentinization of the original peridotite and dunite probably is due, in part, to the rather large apparent thickness of the inferred intrusive sheet. The field relations resemble those in the Twin Sisters Range of northwestern Washington, where serpentinization began along the edges of a large mass of dunite and proceded inward in the presence of water derived from the invaded country rock (Ragan, D. M., in Wyllie, 1967, p 165).

Serpentinization in the Cosmos Hills and Jade Mountains apparently occurred during the last episode of overthrust faulting, perhaps in or continuing until a late stage of that tectonic activity. Pebbles in conglomerate adjacent to serpentinite at Cosmos Mountain are somewhat flattened and stretched, indicating proximity to the uppermost overthrust fault mapped there. However, thin sections of serpentinized conglomerate from within 1 foot of the intrusive rock still display distinct pebble outlines, and individual grains and crystals do not show the extreme undulatory extinction or granulation typical of highly cataclastic rocks or mylonite. This evidence suggests that (1) final hydrothermal activity associated with serpentinization may have occurred after most of the movement along the overthrust fault there had taken place, (2) the exposed contact may be above the main fault, or (3) the serpentinite may have lubricated the fault so that final displacement took place within the serpentinite, which is known to be highly sheared in other parts of this belt.

Veins related to serpentinization -- Veins of hydrothermal origin undoubtedly related to serpentinization of the original intrusive ultramafic rock were observed in several places. Veins of coarse, crystalline talc as much as 4 inches wide are visible near the eastern edge of the main serpentinite body at Asbestos Mountain. Small masses of soapstone were mapped there by Heide, Wright, and Rutledge (1949, fig 10). A 2- to 6-inch vein of talc and carbonate and a 1-foot vein of tremolite-actinolite rock with minor chrome-muscovite are associated with limestone on a north-trending ridge about 2½ miles west southwest of Camp 3. Veins of quartz-carbonate rock containing minor chrome-muscovite and pyrite intrude limestone near a saddle at the top of Shield Mountain. At that locality, a vein system as much as 20 feet wide is composed of several nearly parallel veins as much as 4 feet wide. At Camp 4, a sill-like vein of coarse tremolite-actinolite rock with minor chrome-muscovite intrudes a sequence of schist, marble, and greenschist in a prominent cliff on the east side of the Shungnak River. This vein is at least 50 feet long and as much as 1 foot wide. Smaller lenses and pods of similar material intrude rocks nearby. The main vein there contains numerous bundles and fan-shape aggregates of bright green actinolite crystals as much as 2 inches long, which are much coarser than the actinolite characteristic of greenschist and greenstone in the map area. Hand samples show tiny veinlets of white tremolite 1-2 mm wide cutting across coarse actinolite. Talc is present in rocks on the opposite side of the river. Boulders of serpentinite slabbed at the Stewart jade claim on Dahl Creek display numerous random veinlets of magnetite 1 to 3 mm wide and 1 to 2 inches apart cutting serpentinite that contains disseminated fine-grained magnetite. These veinlets apparently formed during a late stage of the hydrothermal activity related to serpentinization.

Geologic age -- The serpentinite cannot be older than Late Cretaceous and may be as young as Early Tertiary. Field relations along the exposed contact at Cosmos Mountain described above clearly indicate that conglomerate of Late Cretaceous age was altered during the same hydrothermal activity that was responsible for serpentinization of the intrusive rock during its emplacement. Small bodies of similar serpentinite that apparently intrude Cretaceous strata also have been mapped at Cosmos and Bismark Mountains as much as a few hundred feet above the overthrust fault that underlies those strata. Serpentinite float at least 80 feet above this fault on the west side of Wesley Creek indicates that another unmapped lens of serpentinite probably intrudes conglomerate there. The serpentinite now is believed to have been emplaced during a late stage of the overthrust faulting that displaced the strata of Early to Late Cretaceous age. This tectonic activity is believed to have occurred mainly in latest Cretaceous and Early Tertiary time, although its upper limit is uncertain (Structure and Geologic History). The age of the serpentinite, therefore, is reported here as Tertiary (?).

STRUCTURE

The principal geologic structures now recognized in the Cosmos Hills are a dome near intrusive granite in the vicinity of the Kogoluktuk River, an anticline extending westward from the dome toward Wesley Creek, a possible horst which includes the dome and anticline, and a complex window which includes all of those structures. Other structural features include high-angle faults of at least two ages, low-angle overthrust faults, minor folds, crenulations, and widespread lineation.

Dome Near Kogoluktuk River

The dome near the Kogoluktuk River consists of several thousand feet of phyllitic schist and related rocks (Pzs, Pzc, Pzg) which dip outward away from intrusive granite (Kg). The domed rocks appear to have been offset by high-angle faults in several places. The main structure is shown on cross sections A and I (*fig 4B*). The large bodies of greenstone (Pzg) mapped near Crescent and Black Rock Ridges are the youngest of the domed rocks. Their distribution in relation to the granite is slightly asymmetrical, but doming as well as metamorphism apparently accompanied emplacement of the granite. A nearly triangular fault-bounded(?) area of greenstone as much as 1 mile wide in the vicinity of Black Rock Ridge appears to have been strongly tilted after the main doming, but the reason for the tilting is obscure.

Anticline Near Wesley Creek

A major anticline extends westward from Asbestos Mountain to the vicinity of Lone Mountain, but does not involve the main dolomitic limestone (Pzd) exposed there. The fold plunges westward near the head of Wesley Creek, but is flatter and broader near Lone Mountain, where shallow folds are superimposed on the main one. The anticline is offset by the Jay Creek fault west of Lone Mountain, but probably continues westward for at least 2 miles. The long unit of north-dipping limestone (Pzc) mapped south of Aurora Mountain and Pardners Hill is interpreted as part of the northern limb of the anticline, although this limestone is poorly exposed in some places. The apparent absence of equivalent limestone on the southern limb suggests that the limestone either pinched out southward or was offset by unrecognized faults. The queried overthrust fault bounding a nearly circular area at the west end of the anticline is highly speculative, and structure in that area of poor exposure may be quite different from that suggested on the present geologic map.

Horst and Early High-Angle Faults

A major horst formerly was inferred near the Kogoluktuk River where granite and schists were thought to have been upthrown relative to less metamorphosed rocks of the area. Read and Lehner (1959) inferred such a structure about 2 miles wide beneath the valley of the Kogoluktuk. Fritts (*1969, p 20, fig 2*) expanded that concept and inferred that the horst was about 6 miles wide. This structure included the granite and domed strata near the Kogoluktuk River and was bounded by north-trending faults inferred near Lynx and Dahl Creeks. The Lynx Creek fault accounts for marked changes in bedding attitudes and topography near the head of Lynx Creek and for the abrupt eastward termination of garnetiferous greenstone (Pzg), which is in apparent fault contact with nongarnetiferous phyllite near Crescent Ridge and California Creek. Displacement on this fault was thought to be at least 1000 feet. The Dahl Creek fault was mapped to account for the abrupt eastward termination of some 1500 feet of dolomitic limestone (Pzd) at the west bank of Dahl Creek and was inferred to extend northward beneath the valley of Ryan Creek. At that time, the dolomitic limestone was thought to be in normal stratigraphic position above the underlying phyllite (Pzs), although alternative interpretations had been considered and discussed with other geologists. After recognition of a major overthrust fault beneath the dolomitic limestone in 1969, it appeared likely that the Dahl Creek fault is offset by two major overthrust faults, and a fault beneath the valley of Ryan Creek seemed unlikely. If a major horst exists inside the Cosmos Hills window, it apparently is bounded by the Lynx Creek and Jay Creek faults and is at least 11½ miles wide. Displacement on both of those faults is uncertain, but probably is many hundreds of feet. These fractures and others within the possible horst apparently formed during an episode of block-faulting after granite emplacement and metamorphism of the Devonian strata but before overthrust faulting.

Cosmos Hills Window and Low-Angle Overthrust Faults

The most important structure in the Cosmos Hills is a window about 20 miles long and 2 to 8 miles wide here called the Cosmos Hills window. This structure formerly was thought to be bounded by only two major overthrust faults (*Fritts, 1969, fig 1*) but now is known to be much more complex. At least four major overthrust faults have been recognized beneath formations Pzd, Pzup, Pzv, and Ks, respectively. None of these faults completely encircles the window on the map, but collectively the allochthonous rocks above them form the frame of the main structure. If only the uppermost allochthonous strata of Cretaceous age were considered the frame, the structure probably would be best described as a semiwindow.

Field evidence for the overthrust faults is indisputable. The fault beneath unit Pzd was recognized primarily on the basis of field relations near Ruby Creek. Approximately 1500 feet of thinly bedded limestone is characteristic of the lower part of the formation exposed east of that creek, but equivalent limestone is missing on the western side. There is no evidence for an unconformity or conglomerate at the base of the formation in that area, and bedding in the limestone commonly is steeper than the underlying contact now interpreted as an overthrust fault. The fault beneath unit Pzup was recognized primarily on the basis of a marked discordance in bedding between this formation and unit Pzd at Shungnak Mountain and a conspicuous difference in the metamorphic grade of nongarnetiferous phyllite and marble in these formations near the Shungnak River. Evidence for a fault beneath unit Pzv includes a discordance in bedding between this formation and unit Pzs near Stout Mountain and a difference in metamorphic grade between units Pzv and Pzg near Ferguson Peak. Evidence for the fault beneath unit Ks includes structural discordances at Kollioksak Lake and several places along the southern side of the Cosmos Hills, plus a marked difference in the degree of internal shearing in unit Ks compared to underlying Devonian strata. On the northwest side of Cosmos Mountain, where a thin sheet of serpentinite was emplaced along the uppermost thrust, differential weathering has accentuated the position of this fault making it easily recognizable from miles away (*fig 10*).

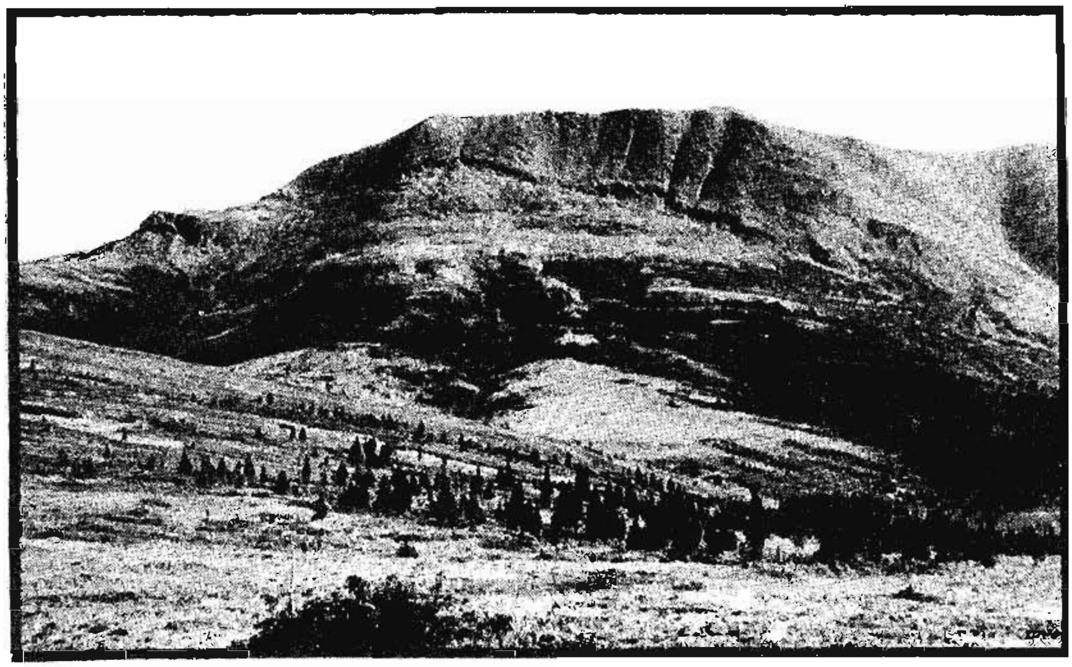


Figure 10. Gently inclined overthrust fault on northwest side of Cosmos Mountain. Separates coarse clastic strata of summit from underlying nearly horizontal limestone.

The direction of movement along the lower three overthrust faults is uncertain, but is believed to have been mainly toward the north-northeast. Evidence for such movement includes the north-northeast orientation of stretched pebbles in phyllite near Bornite and similar orientation of minerals in calcarenite and other Devonian strata throughout the area. Furthermore, the Cosmos Hills trend west-northwest approximately parallel to the regional trend of the adjacent part of the Brooks Range, which is characterized by imbricate overthrust faults that trend west-northwest. The components of stress that produced those faults, as well as the range itself, most likely were oriented north-northeast approximately perpendicular to the range.

A northeast or east-northeast direction of movement of Cretaceous rocks that overlie the uppermost overthrust fault in the Cosmos Hills is indicated clearly by field evidence along the southern side of the window. Lineation and stretched pebbles there in meta-conglomerate and related rocks (Ks) consistently strike northeast to east-northeast. Many of the pebbles and cobbles in these strata are severely deformed and resemble flattened cigars or fish lying on their sides with "heads" facing southwest. The pebbles and cobbles also display striations and slickensides which trend northeast. This kind of deformation can be explained only by shearing in a northeasterly direction. However, the north edge of the Kobuk trough is approximately parallel to the Brooks Range, especially east of the Cosmos Hills (*fig 1*). Thus it is possible that the Cretaceous rocks characteristic of the trough all have been thrust generally northward toward the range, and that shearing in a northeasterly direction occurred relatively late mainly in and near the Cosmos Hills. Northeastward movement in the Cosmos Hills probably is related to tectonic activity in the vicinity of the Seward Peninsula and Hogatza geanticline (*fig 1*).

The evidence available at the present time suggests that the allochthonous rocks in the several imbricate thrust sheets of the Cosmos Hills were thrust against and across previously deformed rocks. The position of the axis of the main anticline within the window is asymmetrical in relation to the frame of that structure. The fold axis is closer to the southern side of the window, and the southern sides of the anticline and dome in it appear to be more highly deformed than their northern sides. This suggests that the block-faulted anticline and dome existed before overlying Devonian rocks were thrust into their present positions. The presence of numerous high-angle faults entirely within some of the allochthonous rocks, especially unit Pzd, indicates that these strata also had been block-faulted prior to overthrust faulting, although recurrent movement along some of the high-angle faults undoubtedly occurred during overthrust faulting.

The evidence at hand also suggests that the metaconglomerate and related rocks of Cretaceous age were thrust against and across a buttress of older and perhaps more indurated rocks. The Cretaceous strata are most deformed along the southern side of the window within a few hundred feet of the underlying overthrust fault. This suggests that the underlying rocks already constituted a structure that was at least slightly convex upward as a result of either (1) original folding of rocks in the main anticline and dome, and subsequent overriding by allochthonous Devonian strata, or (2) gentle arching of the thrust plates that contain Devonian rocks. The abundant evidence of pervasive shearing in the Cretaceous strata and the relative lack of such shearing in the underlying Devonian rocks strongly suggest that the Cretaceous rocks were either (1) poorly consolidated when thrusting began, or (2) more likely to show evidence of shearing because of their coarser grain size. Regardless of the reason for such deformation, the Cretaceous strata closest to the overthrust fault became sheared, crenulated, and metamorphosed to rocks characteristic of the lower greenschist facies during the episode when the Cretaceous rocks were thrust into their present positions, accompanied by emplacement and serpentinization of intrusive ultramafic rock. Highly crenulated phyllitic-looking metaconglomerate is well exposed near the uppermost overthrust fault at Ferguson Peak, and the irregular course of the fault there suggests that the thrust itself may have been slightly folded. On the low ridge west of Kollioksak Lake, where most Cretaceous strata dip gently northward, field evidence clearly indicates that at least some of the Cretaceous rocks closest to the underlying overthrust fault became more steeply inclined as a result of drag along that fault.

The amount of displacement on each of the four main overthrust faults is unknown, but is believed to be at least several miles. Each of the lower three thrust plates extends across the window from south to north with no indication that remnants of the allochthonous formations in them underlie the thrust plates in this area, in spite of the fact that thousands of feet of unit Pzd, for example, have been removed by overthrust faulting. Thus minimum displacements of 5 to 8 miles appear likely along each of the lower three faults, and displacements of 12 miles or more are possible. For example, the northern edge of a belt of metavolcanic rocks equivalent to unit Pzv is approximately 12 miles north of the southern edge of the window (see unit Jv of Patton, Miller, and Tailleur, 1968). Although Cretaceous strata are not exposed along the northern side of the window, the strike and dip of bedding in them along the southern side is oblique to the strike and dip, respectively, of the overthrust fault beneath them. These rocks also appear to have been tilted and perhaps block faulted before or during overthrust faulting, and the field relations suggest that they have been thrust at least several miles across the site of the present window. The total cumulative displacement on the four overthrust faults undoubtedly exceeded 20 miles and may have been more than twice that figure.

Late High-Angle Faults

Late high-angle faults that cut the low-angle overthrust faults as well as the rocks of Paleozoic to Cretaceous age appear to be confined mainly to the east end of the window. These high-angle fractures are believed to be post-Cretaceous, probably Tertiary, in age. Two north-trending faults near the north end of Fish Hook Ridge are characterized by throws of at least several hundred feet and perhaps more than 1000 feet (*cross section A"-A"', fig 4B*). An east-trending fault mapped south of Ferguson Peak accounts for a conspicuous break in topography in an area underlain primarily by Cretaceous metaconglomerate and related rocks. In the field, the general appearance of the metaconglomerate and related rocks on opposite sides of this fault is different. Rocks south of the fault exhibit distinct slaty cleavage and are less sheared than rocks to the north. Throw along this fault, therefore, is believed to be at least several hundred feet and perhaps much more (*cross section A-A', fig 4B*).

Minor Folds and Crenulations

Minor folds and crenulations were observed in many places, especially in the Sungnak quadrangle, but were mapped only where most obvious or abundant. Small anticlines were mapped in greenstone near the head of Harry Creek and in metaconglomerate on Inerevuk Mountain. These folds are as much as 10 feet wide and 4 feet high. Greenstone north of Harry Creek also displays tight chevron folds as much as a few inches high on the flanks of broad folds as much as 5 feet high. Similar chevron folds and crenulations are present in phyllite near Dahl and Wonder Creeks and in schist on the west side of the Kogoluktuk River north of the granite pluton. The significance of these folds is uncertain. Some may have formed during granite emplacement and related metamorphism. Others, especially those which involve Cretaceous strata, presumably formed during the episode of dynamic or dynamo-thermal metamorphism that accompanied overthrust faulting and the emplacement of ultramafic rocks.

METAMORPHISM

A detailed discussion of metamorphism is beyond the scope of this report, but at least two episodes of metamorphism are recognized in this area. An early episode involved progressive thermal metamorphism of rocks adjacent to (especially within 2 miles of) intrusive granite of Early Cretaceous age. Rocks metamorphosed at that time are mainly in the greenschist and albite-epidote-amphibolite facies. The most highly metamorphosed pelitic rocks are schists that contain garnet and biotite, but metamorphosed mafic igneous rocks near the granite contain abundant garnet and coarse new amphibole, which is faintly bluish green in thin section. Very low-grade regional metamorphism of Devonian strata farther from the intrusive granite is believed to have occurred at about the time of granite emplacement. Slight retrograde metamorphism also has affected these rocks, causing such reactions as the partial recrystallization of garnet and biotite to chlorite. None of the rocks examined by the writer contains glaucophane, although this mineral has been found north of the Cosmos Hills (R. B. Forbes, oral communication, 1969). A later episode of dynamic or dynamo-thermal metamorphism and recrystallization of Cretaceous strata to rocks characteristic of the lower greenschist facies occurred during overthrust faulting of those strata and the emplacement and serpentinization of intrusive ultramafic rock. In many of the recrystallized Cretaceous rocks, new muscovite is abundant, and new biotite is present. Antigorite and grossularite or a hydrous variety of that mineral are locally abundant within a few inches of serpentinized intrusive ultramafic rock at Cosmos Mountain.

GEOLOGIC HISTORY

The geologic history of the Cosmos Hills area is divided into two main phases. The first includes Precambrian to Triassic time and is characterized by marine sedimentation and volcanism, especially during the Devonian period. The second includes Jurassic to Recent time and is characterized by intense orogenic activity, especially during the Cretaceous period. This activity included granite emplacement, metamorphism, folding, faulting, formation of the ancestral Brooks Range, and contemporaneous erosion and continental sedimentation. It was followed by glaciation in Pleistocene time. The geologic history, excluding mineralization at Bornite, is summarized as follows:

A. Precambrian to Triassic Time

1. Precambrian and Early Paleozoic events for which no evidence is exposed in or near the Cosmos Hills.

2. Deposition of thousands of feet of marine pelitic and fossiliferous carbonate sediments, including more than 2500 feet of interbedded limestone and dolomite of Middle Devonian age. Contemporaneous volcanic activity with much interlayering of pelitic and volcanic strata and minor fossiliferous limestone of probable Devonian age. The source of the sediments is believed to have been "north" of presentday Alaska, although the relative positions of the North Pole and the Alaskan land mass may have changed appreciably since that time. Emplacement of intrusive mafic igneous rocks now represented by massive greenstone also is believed to have occurred in Devonian time.

3. Late Paleozoic and Early Mesozoic events for which no evidence is exposed in or near the Cosmos Hills. Inferred deep burial of the Devonian strata. Sedimentary rocks of Late Paleozoic and Triassic ages are known to have been deposited north of the Brooks Range and are believed to have extended southward across the Cosmos Hills area.

B. Jurassic to Recent Time

1. Beginning of orogeny in Jurassic time, presumably as a result of continental drift. The early stage of this orogeny involved the gradual uplift of the Brooks Range geanticline, the initial development of a consequent drainage system, and the deposition of sediments shed northward and southward from the elevated region.

2. Emplacement of granite of probable Early Cretaceous age now exposed near the Kogoluktuk River. Contemporaneous doming, formation of the large anticline west of the Kogoluktuk, progressive regional and thermal metamorphism, and emplacement of quartz veins of probable Early Cretaceous age, some of which contained gold (Gold, under Economic Geology).

3. Block faulting of the domed and folded Paleozoic strata in late Early Cretaceous time, with formation of major high-angle fractures such as the Jay Creek fault.

4. Vigorous orogenic activity in the vicinity of the ancestral Brooks Range in late Early and(or) Late Cretaceous time involving thin-skinned tectonics and imbricate low-angle thrust faulting as a result of continued continental drift. The predominant relative direction of movement of thrust plates was from south-southwest to north-northeast as a result of either the underthrusting of "basement" rocks along the north side of the Brooks Range geanticline or the overthrusting of "nonbasement" rocks from the region south of the geanticline. In the Cosmos Hills, this faulting placed thin sheets of block-faulted and slightly to moderately metamorphosed carbonate, pelitic, and volcanic rocks of probable Devonian age over similarly deformed and metamorphosed strata of probable Devonian age which had been intruded by granite of Early Cretaceous age.

5. Erosion of the ancestral Brooks Range and entrenchment of the consequent drainage pattern related to uplift of that range. Contemporaneous deposition of coarse clastic sediments of Early to Late Cretaceous age derived from the metamorphosed strata of the ancestral Brooks Range. Filling of the Koyukuk basin south of that range. Early sediments were partly marine in origin; late sediments were entirely continental in origin. Contemporaneous volcanic activity.

6. Continued or renewed tectonic activity in Late Cretaceous to Early Tertiary time, presumably related to continental drift and events in the vicinity of the Seward Peninsula. Folding and faulting of Cretaceous strata. Emplacement of granodiorite and quartz monzonite within the Koyukuk basin (Miller, Patton, and Lanphere, 1966). Uplift of the Hogatza geanticline, which separates the Koyukuk geosyncline from the Kobuk trough within the former Koyukuk basin *(fig 1)*. Resultant stress directed toward the northeast in the Cosmos Hills. Overthrust faulting of previously deformed Cretaceous strata against and across a buttress of previously deformed Devonian rocks in this area. Contemporaneous dynamic or dynamo-thermal metamorphism, including pervasive shearing and stretching of pebbles and cobbles, and the local crenulation of stretched-pebble conglomerate, especially at Ferguson Peak. Possible gentle folding of overthrust faults near that peak.

7. Emplacement of ultramafic rocks (now represented by serpentinite) along and near the overthrust fault that underlies the Cretaceous strata. This intrusive activity is believed to have occurred during a late stage of the overthrust faulting, perhaps in Early Tertiary time. It was accompanied by the alteration of probable original dunite or peridotite to serpentinite and nephrite, by the formation of grossularite or a hydrous variety of that mineral in adjacent metaconglomerate, and by the emplacement of veins of hydrothermal origin related to serpentinization. Such veins commonly contain one or more of the following materials: coarse-grained tremolite, actinolite, dolomite, and talc, and fine-grained chrome muscovite. Copper mineralization at Bornite is believed to have been affected by, if not directly related to, this hydrothermal activity (Copper, under Economic Geology).

8. High-angle faulting of all thrust plates and underlying rocks in Tertiary time, especially in the eastern part of the Cosmos Hills.

9. Erosion in Middle and Late Tertiary time which produced the present Cosmos Hills window and Ambler Lowland, thereby isolating these hills from the Schwatka Mountains.

10. Slight uplift of the Cosmos Hills and Angayucham Mountains relative to the Schwatka Mountains of the Brooks Range in either Late Tertiary or Quaternary time, resulting in the westward shift of major south-trending rivers as they cross the west-plunging Ambler Lowland.

11. Glaciation in Pleistocene time, including the accumulation of at least 2000 feet of ice in Illinoian(?) time and valley glaciation along major river valleys in Wisconsin(?) time, especially in the northern part of the Cosmos Hills.

12. Recent erosion.

ECONOMIC GEOLOGY

COPPER

Sources of Data

Copper deposits in the Cosmos Hills are confined mainly to dolomitic rocks at Bornite and Pardners Hill. These deposits are discussed here primarily on the basis of previous literature, supplemented by limited observations in the field. The writer did not have access to underground workings at Bornite or to diamond-drill core and geological data collected by mining companies. However, he was permitted to collect samples of copper-bearing rocks from dumps at Bornite and to inspect outcrops in mineralized areas at Old Camp nearby and at Pardners Hill. He also obtained a copy of a dissertation by Runnells (1963) which has not been widely circulated. That report has been listed in more than one published article, and is available to the public at moderate cost. The dissertation is of historical as well as technical interest, because it contains illustrations that help explain the sequence of events at Bornite and the geologic setting there. Pertinent illustrations omitted from a later summary article by Runnells (1969) have been modified for use in the present report mainly because of strong public interest in the area.

History of Exploration

Early prospecting for copper in the Cosmos Hills was done at two main sites shortly after the gold rush of 1898. One was on the northeast end of Pardners Hill, which then was considered part of Aurora Mountain. The other was on the west side of Ruby Creek opposite the present exploration camp at Bornite. Underground work at these sites was done at least as early as 1906 (Smith and Eakin, 1911, p 300-303). At Pardners Hill, a 22-foot shaft penetrated brecciated and slickensided dolomitic limestone that contained chalcopyrite and bornite, and a 30-foot adit penetrated less mineralized carbonate near the base of the hill. At Ruby Creek, a 40-foot adit and 30 feet of drifts penetrated mineralized dolomite near the foot of the west wall of the valley. An open cut approximately 30 x 10 x 7 feet was made in limestone about 150 feet above this adit. Approximately 200 to 300 yards southeast of this cut, a similar one was made near the base of the valley wall. A 55-foot shaft described by Saunders (1953, p 7) also was sunk at Ruby Creek sometime prior to 1948. The shaft and adit at Pardners Hill are shown on the geologic map (*fig 4*), but the early workings at Ruby Creek have been obscured by subsequent prospecting at what now is called Old Camp.

The second main phase of prospecting began in 1948 when Rhinehart Berg discovered radioactivity in copper-bearing vein material collected from old mine dumps at Ruby Creek. The property was examined in 1949 by White (1950) for the U. S. Atomic Energy Commission. An unidentified uranium mineral was found associated with minor sphalerite in a deeply weathered vein 1 foot wide (Matzko and Freeman, 1963, p 39-40). The vein consisted mainly of limonite and subordinate copper carbonates characteristic of the zone of supergene alteration. Primary sulfide minerals at the site included chalcopyrite, bornite, pyrite, galena, and sphalerite. Continued surface exploration by Berg and his associates included trenching, bulldozing, and a little diamond-drilling. Property examinations by Saunders (1953, 1955, 1956) included analyses for copper and uranium, and showed that the copper content was high enough to be of interest to mining companies.

More intense exploration began in 1957 when Bear Creek Mining Company obtained an option on the Berg prospect and vicinity. During the next 13 years, this company collected numerous geochemical samples, conducted EM, SP, and aeromagnetic surveys, and drilled tens of thousands of feet of diamond-drill holes at the two main sites and at other localities in and near the Cosmos Hills. By 1959, 35 holes totaling about 27,000 feet had been drilled to depths as great as 1600 feet (Chadwick, 1960, p 3). By 1961, more than 100 holes had been drilled to depths as great as 2300 feet in an area approximately 5000 x 6000 feet near Bornite (Runnells, 1963, p 1). This drilling revealed a close relationship between dolomite breccia, pyrite, and copper sulfides in an area extending from the Berg prospect (Old Camp) northward and northeastward beneath the valley of Ruby Creek (*fig 11*). Runnells showed the distribution of more than 60 diamond-drill holes and the gentle northeastward dip of the contact (now interpreted as an overthrust fault) beneath the copper-bearing carbonate strata (*fig 12*). His map suggests that the southeastern side of the mineralized area is rather straight and is structurally controlled. Chadwick (1960, p 7-8) stated that a northeast-trending fault zone separates gently north-dipping strata east of the deposit from copper-bearing rocks that are tilted toward the northwest. He also reported that copper mineralization was confined to two main units of dolomite breccia hundreds of feet thick, which are separated by unmineralized phyllite (idem., p 6). Runnells (1963, p 27, 142) referred to the mineralized rocks as the lower and upper dolomite breccias. The lower one is exposed at Old Camp, and the upper one was found by drilling. Runnells showed the relationship between lithology and pyrite content in some of the upper dolomite breccia (*fig 13*) and the vertical distribution of copper sulfides in parts of both breccias (*fig 14*). He apparently relied heavily on previous work by company geologists.

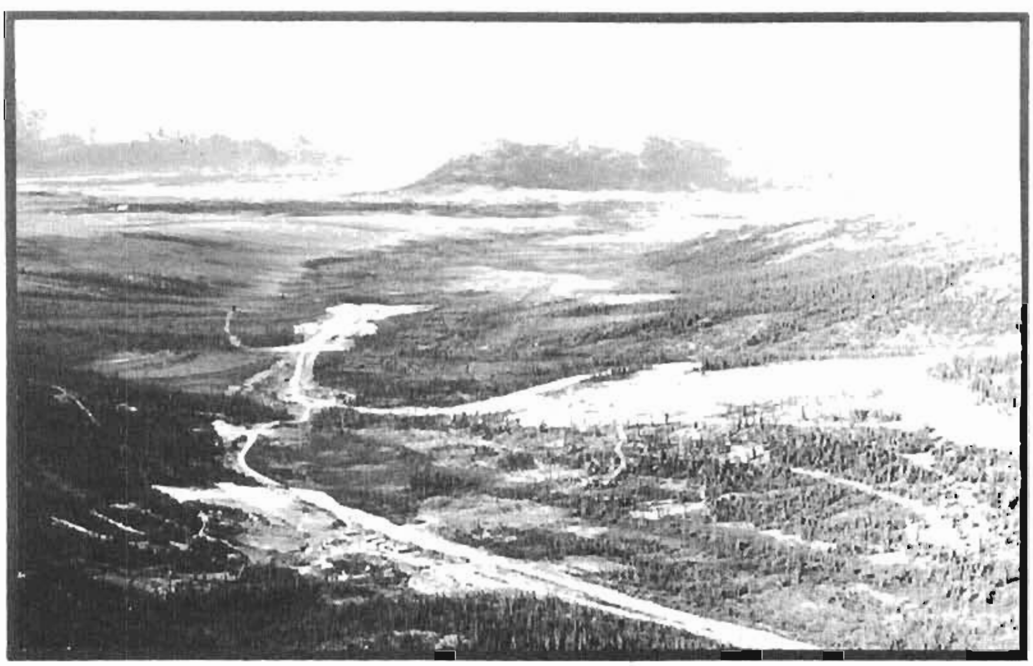


Figure 11. Bornite, Alaska, Viewed from the south in July 1969. Old Camp west of Ruby Creek is at lower left. New camp and shaft east of creek are near center of photograph.

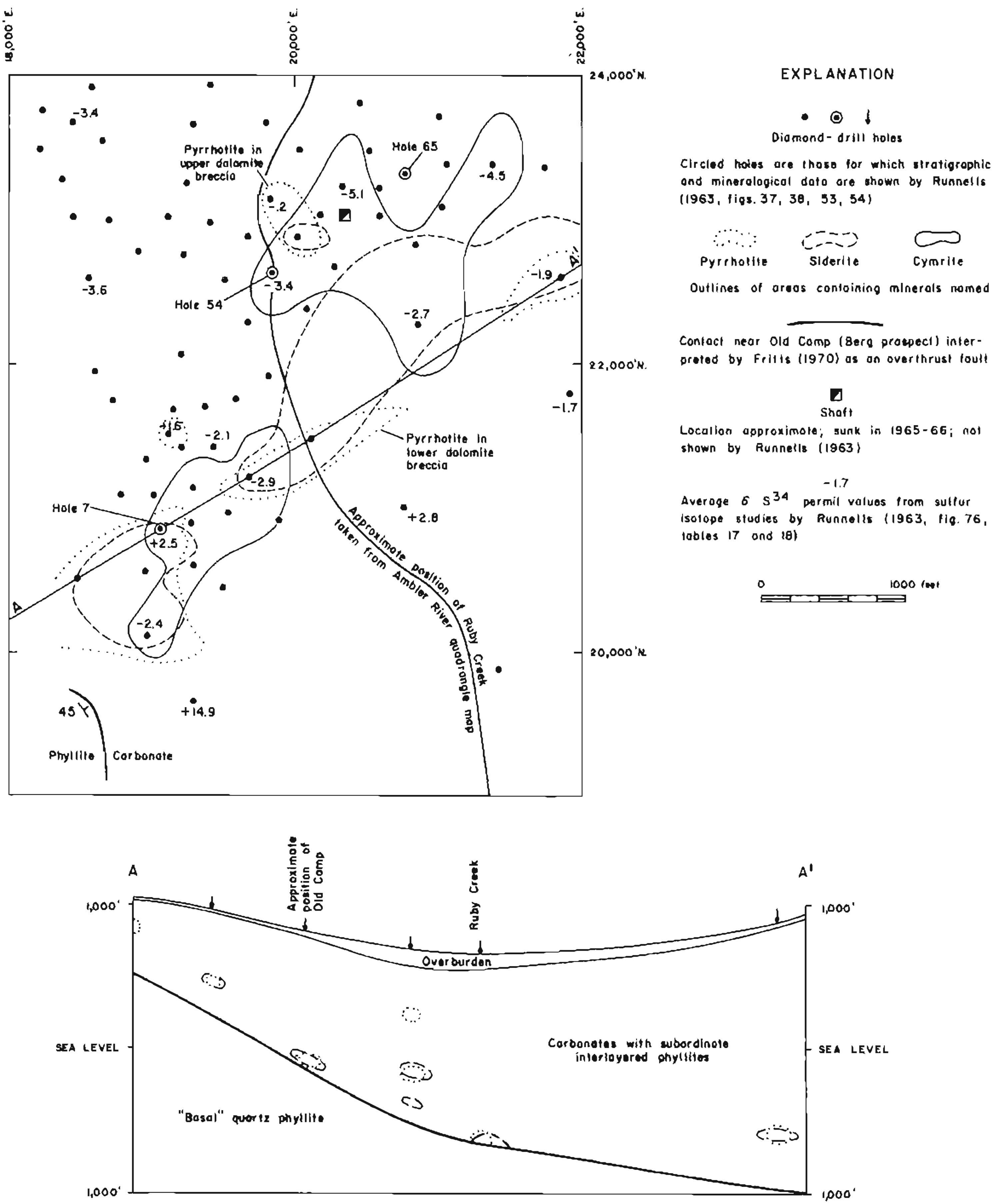


Figure 12. Generalized geologic map and cross section of Bornite area, Alaska (after Runnells, 1963, figs. 50-52, 60, 66, 67)

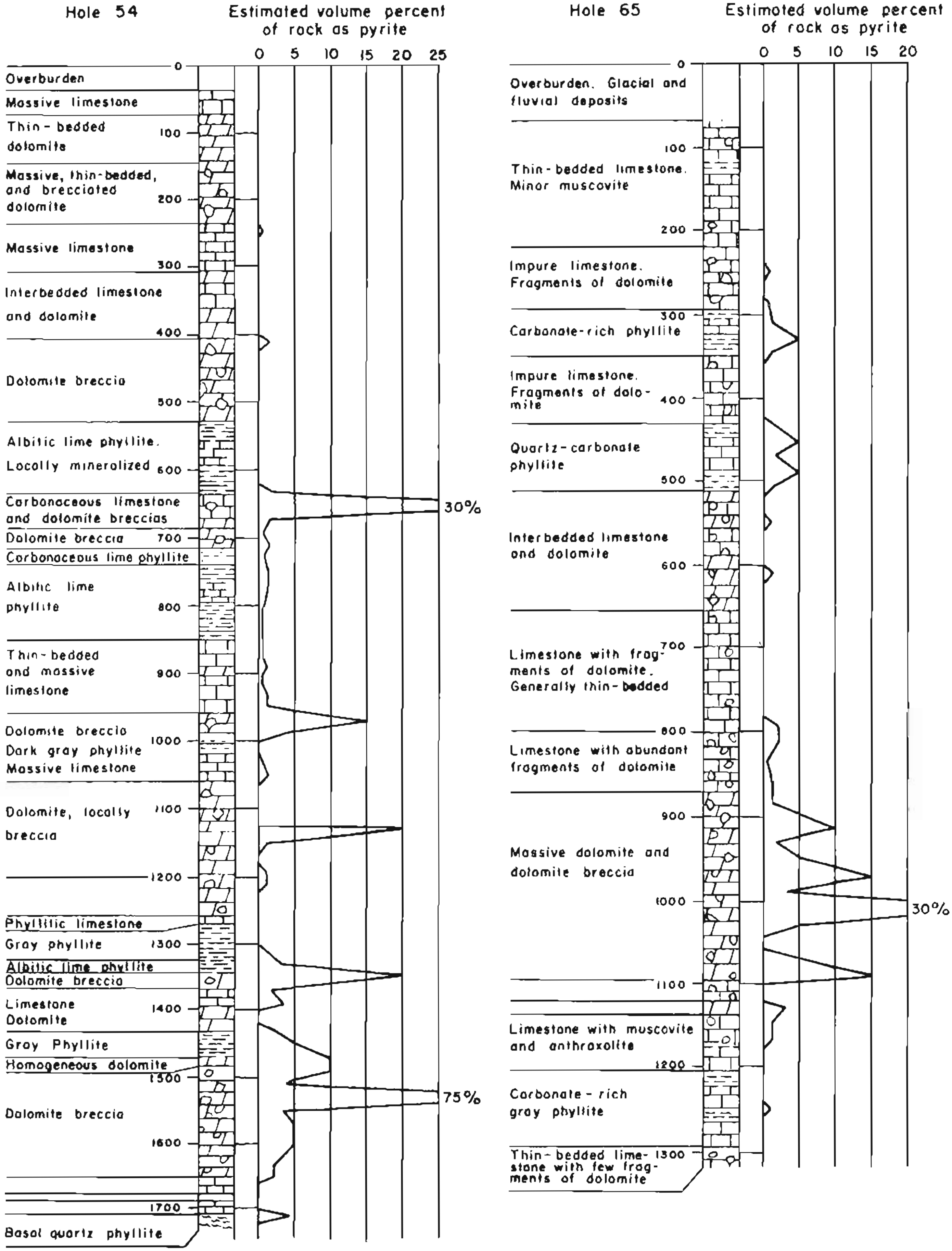


Figure 13. Lithologies and estimated volume percentages of pyrite in core from two diamond-drill holes at Bornite, Alaska (after Runnells, 1963, figures 37 and 38).

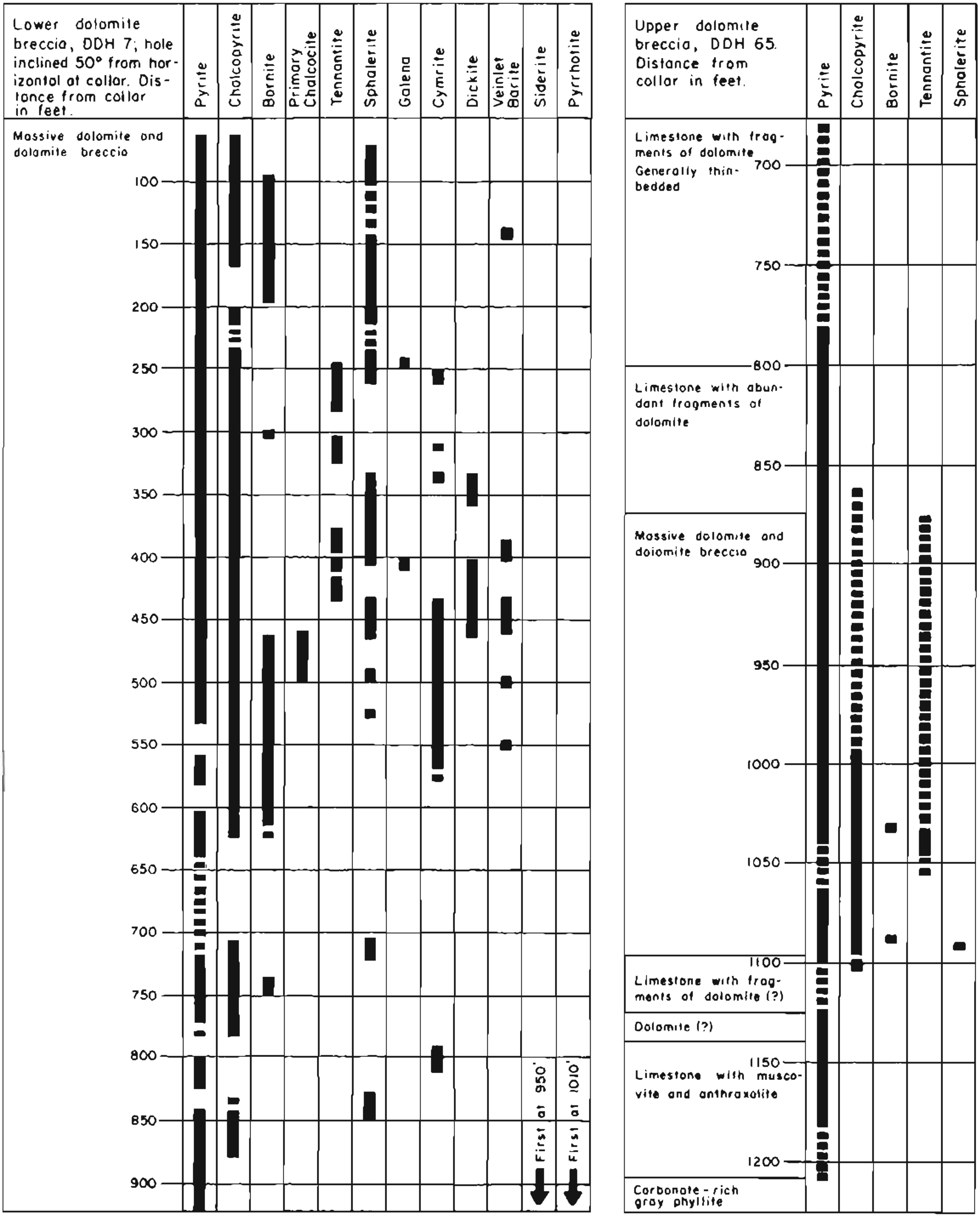


Figure 14. Distribution of sulfides and other minerals in core from two diamond-drill holes at Bornite, Alaska (after Runnells, 1963, figures 54 and 53).

The latest underground exploration at Ruby Creek was done by the Kennecott Copper Corporation during the period 1965-1968. This work was plagued by numerous delays, but was supplemented by more diamond-drilling and various kinds of geophysical surveying. Kennecott acquired control of the mineralized ground in 1963 for $3 million, and, with Bear Creek Mining Company, eventually invested more than $10 million in the area (Knox, 1968, p 16, 17). In 1964, unusually dry weather delayed transportation of heavy equipment via the Kobuk River. However, in November 1965, a vertical shaft 6 x 8 feet was collared at an altitude of about 720 feet on the east side of Ruby Creek (*fig 4*). By October 1966, the shaft had reached a depth of more than 1070 feet (approximately 350 feet below sea level). Drifting was begun at about the 700- and 1000-foot levels apparently to explore parts of the upper dolomite breccia, but this work was hampered by abundant water. The wetness of the main drift "975 feet" below the surface was mentioned by Abercrombie (1969, p 554), and artesian water under considerable natural pressure still flows from drill holes in the valley of Ruby Creek. Underground exploration was delayed further when the unoccupied shaft suddenly became flooded during a "lunch break" on October 27, 1966. In spite of pumping at the rate of 3000 to 3500 gallons per minute, the flooding continued, but the point at which most of the water was entering the shaft finally was located by means of underwater closed-circuit television. In September 1967, the lowermost 23 feet were plugged with cement, which was allowed to set for 30 days. The shaft then was reopened, and underground exploration resumed. All underground work at Bornite, however, ceased during the summer of 1968. In 1969, at least one diamond-drill rig still was active on the surface there, but the camp was used primarily as a base for exploration in and near the western Brooks Range by Bear Creek Mining Company.

Geologic Setting at Bornite

Host rocks

The most favorable host rock at Bornite is dolomite breccia, but limestone breccia, impure limestone, and albitic lime phyllite are mineralized in some places (Runnells, 1963, p 37, 173). Examples of the relative abundance and vertical distribution of these rocks are shown in figure 13.

Dolomite breccia forms bioherms that are interlayered with thinly bedded limestone (idem, p 15). The fresh dolomite breccia is light gray, but weathers to rusty light brown. Fragments as much as 1 inch in diameter have well defined boundaries. The dolomite is even-grained and microcrystalline. Crystals commonly are 0.03 to 0.05 mm in diameter, but locally are recrystallized to 1 or 2 mm (idem, p 38). Finely disseminated carbon retards recrystallization. The rock also contains minor quartz and muscovite. In the mineralized areas it contains abundant pyrite and copper sulfides, which fill pores and spaces between carbonate crystals and rock fragments (idem, p 38).

Limestone breccia is medium to dark gray, and consists of dolomite and calcite fragments in a calcite matrix. Angular to subrounded dolomite fragments about 1 inch in diameter are typical. They are characterized by ragged edges, and are penetrated by irregular fingers of calcitic matrix. Fragments show excellent algal banding, cup corals, mollusk shells, and honeycomb corals (idem, p 41-43). The rock matrix is composed of sand-size grains of calcite, which are elongate parallel to regional lineation. Amorphous carbon, muscovite, and pyrite also are present. Muscovite commonly is parallel to bedding and tends to wrap around lithic fragments.

Thinly bedded limestone forms units as much as several hundred feet thick along the periphery of the main copper-bearing area (idem, p 43). This rock is characterized by the grain size and sandy texture of typical calcarenite. Grains commonly are elongate parallel to regional lineation. Calcite usually is dominant over dolomite. The rock also contains significant amounts of muscovite, quartz, and carbon, and grades into phyllite. The limestone contains minor pyrite.

Albitic lime phyllite is subordinate to, but interlayered with, the main carbonate rocks (idem, p 45). It is interpreted as metatuff or tuffaceous metasedimentary rock. Its presence at more than one stratigraphic position suggests intermittent volcanism or the occasional reworking of volcanic debris during a long episode of carbonate sedimentation (idem, p 46). The albitic lime phyllite consists of alternating layers a few millimeters thick, which contain mixtures of calcite, dolomite, albite, muscovite, quartz, chlorite, and pyrite (idem, p 33). Grain size commonly is less than 0.1 mm (idem, p 35). Chlorite forms less than 5% of the rock, but crystals as much as 0.2 mm in diameter are typical. Ellipsoidal, well twinned albite crystals 0.1 to 1.0 mm in diameter are scattered along foliation planes, and constitute as much as 50% of the rock. Many of them contain tiny fibrous crystals of possible actinolite (idem, p 36). In some drill holes, albite is most abundant near copper sulfides (idem, fig 55, p 145), but the albitic lime phyllite is mineralized primarily where the rock is adjacent to mineralized carbonate breccia (idem, p 147). Soda now present in the albite is believed to have been present in the rock prior to copper mineralization (idem, p 46).

The host rocks at Bornite contain no diagenetic chert (idem, p 47). Silica is present in the form of quartz, but this mineral probably is only partly detrital in origin (idem, p 46). At least some of the quartz may have formed as a result of the recrystallization of original sedimentary or volcanic debris (idem, p 47). In the Angayucham Mountains, on the other hand, well bedded chert is locally conspicuous within a thick sequence of pillow lavas that are believed to be equivalent to the metavolcanic rocks exposed on Moose Mountain northeast of Bornite.

Dolomitization and calcitization

Dolomitization and calcitization (or the local nonmetamorphic recrystallization of calcite) are believed to be diagenetic or authigenic processes completely unrelated to sulfide mineralization (Runnells, 1963, p 173, 175). The presence of dolomite fragments in limestone breccia as well as dolomite breccia indicates that dolomitization of certain reef strata had occurred prior to their partial breakup and incorporation in younger sediments within the main carbonate sequence. Patchy recrystallization of the matrix of dolomite breccia to dolomite crystals about 1 mm in diameter and the formation of fibrous dolomite veinlets are believed to reflect authigenic processes that occurred shortly after dolomitization of the original sediments (idem, p 178). Although pyritic dolomite breccia is the preferred host rock for copper mineralization at Bornite, no evidence has been reported to relate that mineralization to dolomitization. Large volumes of sulfide-free dolomite are present in the area, and some copper mineralization is found in breccias that have a calcite matrix (idem, p 173). In general, rocks that are extensively recrystallized are not well mineralized (idem, p 178). Recrystallization of calcite and the emplacement of calcite stringers were common along the tattered edges of dolomite fragments in limestone breccia, and also occurred in thin-bedded limestone (idem, p 173). Recrystallization of the calcite matrix surrounding some carbonate fragments appears to have been guided by fractures, and has produced rocks that resemble tectonic breccia (idem, p 176).

Veinlets

A complex and extensive system of veinlets has been recognized at Bornite (Runnells, 1963, p 83, 84). Most are fracture fillings, but the earliest are replacements of host rock. Dolomite, calcite, and quartz veinlets tend to be most abundant in dolomite, limestone, and phyllite, respectively (idem, p 105). Veinlets are listed here in order of decreasing age.

Pre-copper veinlets:

(1) Fibrous gray dolomite; authigenic replacements; gradational boundaries.

(2) Siderite; post-lithification fracture fillings; not common.

(3) Granular white dolomite; common in dolomitic host.

(4) Calcite-quartz-dolomite; most common, especially in dolomitic host; quartz may be euhedral; cut by copper sulfides.

Post-copper veinlets:

(5) Barite-calcite-fluorite; especially common in albitic lime phyllite; cut masses of copper sulfides; may contain euhedral quartz and chalcopyrite; believed to represent a late stage of copper mineralization (idem, p 105).

Supergene veinlets:

(6) Goethite-calcite; common within a few hundred feet of the present ground surface; exhibit coarse banding parallel to walls.

Open unmineralized fractures, with slickensided walls characterized by displacements measured in millimeters, are believed to be post-copper in age (idem, p 102).

Shape of copper sulfide bodies

Copper sulfide minerals at Bornite are concentrated in units characterized by greater horizontal than vertical extent within the favorable stratigraphic hosts. The minerals form irregular lenticular concentrations approximately parallel to bedding, and are best termed concordant or stratiform deposits (Runnells, 1963, p 132; 1969, p 80).

Wallrock alteration

Wallrock alteration at Bornite has been exceedingly mild. The wallrocks display no evidence of the formation of calc-silicate minerals, silicification, or extensive bleaching (Runnells, 1969, p 85, 86). Delicate fossils have been beautifully preserved adjacent to masses of pyrite and copper sulfides (Runnells, 1963, p 246). There have been no major changes in the carbonate host rocks. The presence of siderite and pyrrhotite, in addition to abundant early pyrite, reflects variation in the iron content of the host rocks, but these minerals are not known to be genetically related to the copper mineralization. The presence of cymrite is interpreted as evidence for the migration of barium prior to copper mineralization, but a genetic relationship between the cymrite and copper sulfides is not clearcut (idem, p 156).

Minerals at Bornite

Siderite

Siderite forms scattered massive replacements of carbonate rock, in addition to relatively uncommon veinlets that cut pyrite and ankeritic carbonate (Runnells, 1963, p 184). Aggregates of siderite crystals averaging about 0.05 mm in diameter are typical. This mineral reportedly is most abundant in the lower dolomitic strata along the southeastern side of the main drilled area, but also is present in core from at least one hole that penetrated the upper dolomite breccia (*fig 6*). Siderite constitutes as much as 95% of some drill-core samples by weight (idem, p 188). It commonly is associated with pyrrhotite (idem, p 187). The siderite cuts early pyrrhotite, but is cut by veinlets of late pyrrhotite, pyrite, dolomite, calcite, chlorite, and quartz, either alone or in mixtures (idem, p 190). Ankeritic carbonate associated with siderite was found in the lower part of diamond-drill hole 7 at Old Camp (idem, p 182, 187).

The origin of the siderite is uncertain, but it is believed to be pre-copper in age. Runnells (1963, p 191) considered the possibility that the siderite-ankerite-pyrrhotite assemblage might represent a sedimentary facies deposited in a deep-water, sulfur-poor environment. However, the siderite-bearing strata are associated with reef breccia and calc-arenite undoubtedly deposited in a relatively shallow marine environment. The general geologic setting and replacement characteristics of the siderite seem to rule out the possibility of a deep-water sedimentary origin. Runnells (idem, p 184) pointed out that the siderite is younger than fibrous dolomite veinlets, but older than calcite-quartz-dolomite veinlets and veinlets that contain pyrrhotite, pyrite, chlorite, quartz, or mixtures of those minerals. The available evidence suggests that the siderite was emplaced sometime after dolomitization of the carbonate rocks but before copper mineralization.

Pyrrhotite

Pyrrhotite is found mainly in relatively sparse, massive, siderite-rich (iron-rich) but otherwise poorly mineralized carbonate breccia and related strata beneath the main copper deposits (Runnells, 1963, p 61, 143, 251). This mineral, like siderite, apparently is restricted to the southeastern side of the most thoroughly drilled area (idem, p 134, 138). The pyrrhotite generally forms aggregates of crystals 0.05 to 0.5 mm in diameter in the carbonate rocks, but also forms metacrysts in albitic lime phyllite, plus a few veinlets. The aggregates of pyrrhotite crystals commonly are veined and surrounded by mixtures of fine-grained pyrite and siderite (idem, p 61). Pyrrhotite has not been reported in the zonal arrangement of the main copper sulfides, but it does contain minor chalcopyrite in some places (idem, p 251, 254).

The origin of the pyrrhotite is uncertain, but it appears to be pre-metamorphism and pre-copper in age. Some of the pyrrhotite is oriented parallel to regional lineation of the host rocks, especially in albitic lime phyllite, but inclusions of chalcopyrite are unoriented (idem, p 61, 251). Pyrrhotite is the only metallic mineral other than pyrite to exhibit a texture indicative of deformation or growth under stress. The pyrrhotite crystallized almost exclusively in the monoclinic polymorph, which suggests that it formed at a temperature not over 325° C (idem, p 265). This is compatible with temperatures believed to prevail during low-grade greenschist facies metamorphism. Runnells (idem, p 134, 191) mentioned the possibility that the lineated pyrrhotite is sedimentary or early diagenetic in origin, or was derived from pyrite of such origin. He recognized that veinlet pyrrhotite could not be sedimentary in origin, but suggested that it could reflect remobilization of earlier pyrrhotite during metamorphism (idem, p 223).

Its association with siderite suggests slight enrichment of certain carbonate strata in iron prior to copper mineralization.

Cymrite

Cymrite (pronounced Kumrite) is a rare hydrous barium aluminum silicate found only in Wales (Cymru in Welch), at Bornite, Alaska, and near the head of Bonanza Creek in the Wiseman quadrangle, Alaska (Runnells, 1963, p 151, 152). Volumetrically cymrite at Bornite is unimportant, as it forms only 2 or 3% of the rock where most abundant (idem, p 154). However, it is closely related spatially to copper mineralization there. It usually forms scattered tiny colorless to dark green or brown hexagonal plates as much as 3 mm in diameter replacing dolomitic, sideritic, and ankeritic host rocks, and is bordered by recrystallized carbonate (idem, p 152-154). It also has been observed in contact with pyrite, fluorite, quartz, and chlorite (Runnells, 1964, p 160, 164). At Old Camp (*fig 14*) cymrite appears to be most abundant in rocks that contain primary chalcocite and bornite below the zone of supergene alteration (Runnells, 1963, p 143). In the supergene zone, cymrite is converted to a mixture of barite and kaolinite (idem, p 161). Pseudomorphs of copper sulfides after cymrite show that this mineral is pre-copper in age (idem, p 154-156).

The presence of cymrite at Bornite is believed to indicate slight early enrichment of wallrock in barium, although it shows no zonal relationship to the copper sulfides (idem, p 156). This mineral appears to be primarily a product of solution alteration of impure carbonate host rocks prior to copper mineralization, with silicon, aluminum, and barium derived from adjacent wallrock (Runnells, 1963, p 156; 1969, p 163). Barium is absent or rare in unmineralized carbonate rock in this area, but is present in quantities as large as 40,000 ppm in the copper-bearing strata, which contain minor cymrite and veinlet barite (Runnells, 1963, p 159, 160). In contrast, phyllitic rocks in the area average about 2400 ppm barium regardless of location (idem, p 159).

Pyrite

Pyrite is the most abundant sulfide at Bornite (Runnells, 1963, p 48, 49). It is common in phyllite and is especially abundant in dolomite breccia. Pyrite usually forms 1 to 20% of phyllitic rocks by volume, but rarely forms as much as 50% of black carbonaceous phyllite (Runnells, 1963, p 48). Pyrite also forms as much as 75% of core samples from dolomite breccia (*fig 13*). The mineral commonly is extremely fine-grained, which led to its early misidentification as marcasite (Chadwick, 1960, p 7). Pyritohedra 2 to 10 microns (0.0002 to 0.001 mm) in diameter are most typical, but some of the pyrite reportedly has recrystallized to cubes 2 or 3 mm in diameter. Octahedra as much as 1 mm in diameter are visible in bornite-rich samples collected from dumps near the new shaft in 1969.

Early pyrite is believed to be sedimentary or early diagenetic in origin. In phyllite, this mineral commonly exhibits the framboidal texture characteristic of sedimentary pyrite. Aggregates of tiny pyrite crystals usually are elongate parallel to regional lineation, clearly indicating that the mineral is pre-metamorphism in age (Runnells, 1969, p 78, 79). In dolomite breccia, pyrite commonly is confined to the matrix surrounding lithic fragments, and it displays colloform-like concentric banding indicative of precipitation from the colloidal state (Runnells, 1963, p 49). In limestone breccia, pyrite usually is confined to the periphery of dolomite fragments (idem, p 51). The available evidence suggests that the deposition of early pyrite followed dolomitization of reef carbonates, and probably accompanied and (or) followed the redistribution of reef debris. Some of the pyrite surrounding dolomite fragments, however, can be interpreted as late or introduced.

Late pyrite is believed to have been deposited in the carbonate rocks during copper mineralization long after sedimentation, perhaps as a result of remobilization of early pyrite by hydrothermal solutions (Runnells, 1963, p 244, 245, 259; 1969, p 80). In the mineralized carbonate rock, much pyrite is veined by copper sulfides, but veinlets containing subhedral pyrite locally cut chalcopyrite as well as dolomitic and sideritic wallrock (Runnells, 1963, p 239). The textures suggest that most of the pyrite in dolomite breccia was present before the introduction of copper sulfides (idem, p 244, 256), but veinlet pyrite appears to be epigenetic in origin (Runnells, 1969, p 79).

Evidence listed by Runnells (1963, p 243, 244) in favor of a hydrothermal origin for some of the pyrite at Bornite is as follows:

(1) an isotopic dissimilarity between early framboidal pyrite and later veinlet pyrite in carbonate breccia,

(2) cross-cutting relationships between pyrite stringers and dolomite fragments that they intrude,

(3) concentrations of pyrite along the rims of dolomite fragments regardless of the composition of the adjacent matrix,

(4) the abundance of pyrite in the matrix of some carbonate breccias, and

(5) the presence of pyrite in dolomite-calcite-quartz veinlets that cut dolomitic wallrock.

Chalcopyrite

Chalcopyrite is the most abundant copper mineral at Bornite, and chalcopyrite-pyrite is the most important potential ore assemblage (Runnells, 1963, p 51, 138). This mineral crosscuts and replaces the matrix of dolomite breccia, fills spaces between carbonate crystals, and forms the matrix around masses of pyrite (Runnells, 1963, p 51, 53; 1969, p 79). Massive replacement of carbonate host rock by chalcopyrite is less common (Runnells, 1969, p 79). Chalcopyrite also occurs with bornite filling fractures in pyrite and carbonates. In limestone breccia, chalcopyrite tends to follow the margins of dolomite fragments (Runnells, 1963, p 175). It also surrounds dolomite fragments in breccia characterized by a pelitic matrix in hand samples collected from dumps at Bornite in 1969. The chalcopyrite usually forms anhedral crystals 0.01 to 0.3 mm in diameter, but in vugs and open veinlets it forms anhedral crystals 2 to 3 mm in diameter. Vein-quartz float collected at Pardners Hill in 1969 contains euhedral chalcopyrite resting on euhedral quartz, and both are overlain by malachite and azurite of supergene origin. The presence of tiny unoriented inclusions of chalcopyrite in lineated pyrrhotite suggests that copper mineralization at Bornite occurred at a temperature no more than 325° C some time after regional metamorphism (Runnells, 1963, p 251).

Bornite

Bornite is the second most important copper mineral at this locality. Volumetrically it is important only in the richer zones of copper mineralization (Runnells, 1969, p 79). It is more abundant than chalcocite and locally forms more than 50% of the mineralized rock by volume (Runnells, 1963, p 56). It commonly is intergrown with chalcopyrite or chalcocite. The bornite reportedly contains minor germanite and galena crystals 0.02 to 0.03 mm in diameter. It occasionally is found in vuggy carbonate veinlets. In hand samples collected from dumps at Bornite, this mineral is intimately intergrown with chalcopyrite and pyrite. The bornite appears to crosscut and surround both of these sulfides as well as fragments of dolomite breccia. Irregular veinlets of chalcopyrite and bornite in phyllite display narrow rims of calcite.

Chalcocite

Primary chalcocite is centrally located within the copper-bearing rocks at Bornite, but never constitutes more than 15% of the total sulfides in a given sample (Runnells, 1963, p 58). It commonly veins and replaces bornite, but is less conspicuous. The primary chalcocite is steel gray and coarser than sooty chalcocite characteristic of the zone of supergene alteration. Its primary origin is suggested by its central location in relation to other copper sulfides and its association with cymrite in diamond-drill hole 7 at Old Camp (idem, p 56, 166).

Tennantite-tetrahedrite

Tennantite-tetrahedrite reportedly is sparingly present in many specimens of drill core, but is only rarely the dominant sulfide (Runnells, 1963, p 58; 1969, p 79). It commonly is 0.2 to 0.3 mm in diameter. It generally is intimately intergrown with chalcopyrite, but also is associated with sphalerite. The tennantite-tetrahedrite generally is absent from rocks that contain bornite or chalcocite (Runnells, 1969, p 78).

Sphalerite

Sphalerite is the most ubiquitous sulfide at Bornite, but generally is not abundant (Runnells, 1963, p 60; 1969, p 79). It is only rarely the main sulfide. It forms crystals a few tenths of a millimeter in diameter, which display various colors. The sphalerite commonly is intergrown with minor galena, but also is associated with chalcopyrite and pyrite.

Galena

Galena at Bornite commonly is associated with sphalerite, but is much less abundant (Runnells, 1963, p 65). It usually forms crystals only a few hundredths of a millimeter in diameter, but contains inclusions of pyrite, sphalerite, and carbonate. It differs from sphalerite by forming blebs (with germanite) in bornite.

Other primary sulfides

Minor amounts of carrollite, germanite, and marcasite also were reported from Bornite (Runnells, 1963, p 65, 67). Carrollite, a cobalt-copper sulfide, is associated with pyrite, chalcopyrite, bornite, and pyrrhotite, but rarely exceeds a few hundredths of a millimeter in diameter. Germanite, a germanium-bearing copper-iron sulfide, forms tiny blebs in bornite, but rarely exceeds 0.03 mm in diameter. Marcasite, the least abundant sulfide, was observed only under very high magnification (1000x) replacing pyrite in the pyrite-pyrrhotite-siderite assemblage.

Supergene minerals

Supergene minerals at Bornite include the sulfides djurleite, covellite, digenite, and sooty chalcocite, and other minerals such as goethite, calcite, malachite, azurite, native copper, native silver, cuprite, kaolinite, aragonite, and barite (Runnells, 1966). The supergene sulfides apparently were recognized mainly in diamond-drill core, but small amounts of malachite and azurite are visible in dolomite breccia at Old Camp and Pardners Hill. A few angular boulders 2 or 3 feet in diameter containing abundant goethite associated with magnetite and very fine-grained pyrite were observed by the writer on a prominent dolomite knob immediately south of Old Camp. Comparable boulders characterized by colloform goethite and euhedral magnetite crystals as much as 1 mm in diameter are especially abundant on the flanks of Lone Mountain. Runnells (1963, p 76, 77) reported that tiny octahedra of native copper at Bornite commonly are associated with goethite, whereas wires of native silver as much as 3 mm long are associated with supergene sulfides that replace tennantite. Neither of the native metals is abundant.

Radioactive mineral

Radioactive material at Bornite consists mainly of clusters and irregular stringers of tiny dark particles, which have been referred to informally as sooty pitchblende. However, the material is so fine-grained and scarce that pitchblende could not be verified by normal laboratory methods (Runnells, 1963, p 69). This material occurs mainly in the matrix of carbonate breccias, but also forms stringers parallel to bedding in at least one micaceous rock.

Anthraxolite

Anthraxolite, a black, brittle, nonradioactive substance formed from organic matter present in the original carbonate strata, is ubiquitous but volumetrically unimportant (Runnells, 1963, p 121). It is pre-fibrous-dolomite in age (idem, p 129). It occurs as scattered blebs and veinlets, and occasionally is mixed with pyrite, especially along stylolites (idem, p 119). Its temperature of formation probably is less than 250° C (idem, p 130).

Precious metals

Precious metals such as gold are present only in trace amounts at Bornite (Chadwick, 1960, p 8). This suggests that copper mineralization and gold mineralization in the Cosmos Hills were completely unrelated processes.

Copper Mineralization at Bornite

Zoning suggesting migration of copper

Both horizontal and vertical zoning of sulfides have been recognized at Bornite, although the vertical zoning is debated by some geologists familiar with the area. In general, a roughly concentric arrangement of zones characterized by pyrite (outermost), chalcopyrite, tennantite-tetrahedrite, bornite, and chalcocite (innermost) reflects an increase in the copper:iron ratio from the margins to the core of the main copper deposit (Runnells, 1963, p 238; 1969, p 82). In plan view, pyrite and chalcopyrite reportedly are most widespread, and sphalerite is nearly so (Runnells, 1969, p 80). Bornite and tennantite-tetrahedrite are coextensive but somewhat restricted. Galena and chalcocite are even more restricted to relatively small areas. Vertical zoning reportedly is well developed, but subtle, with much interference of concentric zones in any given drill hole (Runnells, 1963, p 138, 141; 1969, p 80). In figure 14, for example, chalcopyrite appears to be confined to the inner parts of pyrite-bearing zones, and bornite and tennantite-tetrahedrite occupy positions within the chalcopyrite-bearing zones. Ignoring pyrite, which is at least partly sedimentary or early diagenetic in origin, the distribution of copper sulfides suggests that chalcopyrite, tennantite-tetrahedrite, bornite, and chalcocite were deposited in that general order, with the youngest and richest copper mineral closest to channelways along which mineralizing fluids migrated (Runnells, 1963, p 238).

Sulfur isotopes suggesting hydrothermal activity

The study of sulfur isotopes currently is applied to sulfide mineral deposits as a means of determining origin. The lightest of four known sulfur isotopes (S^{32}) constitutes approximately 95.1% of the earth's sulfur, whereas the S^{34} isotope accounts for about 4.2% (Runnells, 1963, p 195). Variations in the S^{34}/S^{32} ratio in sulfide minerals relative to that of a standard (troilite of the Canyon Diablo meteorite) commonly is given in terms of δS^{34} permil (parts per thousand). Positive or negative values of δS^{34} indicate sulfur that is heavier or lighter, respectively than the standard (idem, p 196). Certain mineral deposits show a general relationship between range in δS^{34} values and mode of origin. Runnells (1963, fig 71, p 204) gave the following examples: sedimentary sulfides (-43 to +43), red-bed copper deposits (-47 to +3), hydrothermal lead-zinc deposits of Tintic, Utah (-23 to +10), and others. His study of sulfides from Bornite showed that framboidal pyrite in phyllite is characterized by a range of 28 permil, with a mean value of -9.8, while sulfides from copper-bearing carbonate rocks are characterized by a range of 24 permil, with a mean value of -1.3 (idem, p 264). He emphasized that the marked difference between sulfur in early pyrite and sulfur in the main copper deposit reflects a similar difference in origin (idem, p 226). He stressed the similarity between sulfur isotopes of the copper deposit at Bornite and those of the Tintic district, despite the difference in metal content in the two areas. He concluded that copper at Bornite is of low temperature, magmatic, hydrothermal origin (idem, p 232, 263, 264). He visualized a single episode of hypogene copper mineralization, with temperature probably not more than 300° or 325° C (idem, p 236, 265). He also mentioned that an apparent southward increase in the average δS^{34} values in this area (*fig 12*) suggests movement of mineralizing solutions from south to north, but stated that the data at hand are too sparse to be definitive (idem, p 223, 225).

Previous interpretations of origin, source, and age of copper

A syngenetic or modified syngenetic origin for the copper deposit at Bornite has been favored by at least some of the exploration geologists familiar with the area. Advocates of this interpretation have stressed the presence of sedimentary sulfides, such as colloform and framboidal pyrite, and the apparent lack of an alteration halo around the main copper deposit. They visualize the deposition or precipitation of iron and copper sulfides in relatively quiet reducing environments within a reef complex in Devonian time. However, the textural, veining, and zoning relationships described above strongly suggest that the copper minerals at Bornite were at least mobilized and redeposited during hydrothermal activity in post-Devonian time, if not deposited directly from hydrothermal solutions.

Published interpretations concerning the source and age of the copper deposit at Bornite favor an epigenetic origin and Cretaceous or younger age. Chadwick (1960, p 8) visualized the release of this metal from a copper-rich mafic lava flow or sill and the subsequent migration of copper to permeable dolomite breccia during regional metamorphism. He interpreted the deposition of copper minerals there as a more or less post-metamorphism process. Runnells (1963, p 232, 233) stressed the epigenetic origin of the copper, partly on the basis of the sulfur isotope studies described above, but considered several possibilities concerning its source. One involved the migration of copper- and pyrite-bearing ooze to the dolomite breccia. Another involved the solution and migration of copper from phyllites, which are known to contain a few hundredths of a percent copper in this area. He concluded, however, that the copper mineralization was related to intrusive mafic rocks such as the small body of metagabbro exposed about 9000 feet southeast of Bornite, which he then considered post-metamorphism in age. In a subsequent article, Runnells (1969, p 77) still advocated derivation of epigenetic copper from mafic igneous rocks, but stated that its source is unknown.

Runnells (1963, p 247, 248) also discussed briefly the pressure and temperature conditions under which monoclinic pyrrhotite could have formed and under which siliceous carbonate rock could have recrystallized without the formation of wollastonite. Monoclinic pyrrhotite is present at Bornite, but wollastonite is absent. Although the data he discussed are inconclusive, they are compatible with the concept that mineralization at Bornite could have occurred at a temperature of less than 325° C and a depth of as much as a few miles.

Present interpretation of origin, source, and age

The copper deposit at Bornite appears to be structurally as well as stratigraphically and lithologically controlled. The copper-bearing rocks of greatest interest are block-faulted, allochthonous, dolomitic strata (especially dolomite breccia) of Middle Devonian age which are underlain and overlain by major overthrust faults (*cross sections A, D, and E, fig 4B*). In the field, copper and iron minerals seem to be most abundant and conspicuous where dolomite breccia is relatively close to the overthrust faults, although at least some of the pyrite in the rock appears to be of sedimentary origin. In contrast, equivalent but iron-poor dolomitic and brecciated strata far above the underlying overthrust fault east of Bornite are not known to contain appreciable quantities of copper.

The writer believes that the present copper deposit at Bornite is low-temperature-hydrothermal in origin and post-metamorphism in age, as suggested by Runnells. If so, it cannot be older than Early Cretaceous but can be as young as Late Cretaceous or Early Tertiary. The available evidence suggests that the copper deposit achieved its present form and position during widespread hydrothermal activity now known to have occurred at the time of emplacement and serpentinization of ultramafic rocks in and near the Cosmos Hills. Appropriate conditions or relatively low temperature and moderate pressure undoubtedly existed there during the latest overthrust faulting with which the serpentinite of the area was associated. At least one small body of serpentinite intrudes the main dolomitic limestone at Aurora Mountain, and veins of hydrothermal origin related to serpentinization are exposed at several localities in the area. Some of the veins contain abundant carbonate and could be related to carbonate-bearing veinlets of hydrothermal origin found at Bornite. Although the serpentinite of the Shungnak district is not known to contain large quantities of copper sulfide minerals, it does contain sulfur in the form of pyrite. Furthermore, in 1969 the writer observed malachite and steel gray chalcocite in quartz rubble derived from metaconglomerate exposed near serpentinite on the northwest side of Cosmos Mountain. Quartz veins containing chalcopyrite, malachite, and azurite also have been reported cutting Cretaceous metaconglomerate near a major fault in the Angayucham Mountains about 20 miles east southeast of the Cosmos Hills (Patton and Miller, 1966).

In summary, the evidence at hand suggests that the copper sulfides at Bornite either were deposited or were mobilized and redeposited there during the hydrothermal activity responsible for serpentinization elsewhere in the district. Copper mineralization apparently was preceded by slight enrichment of the host rocks in iron and barium. In the opinion of the writer, the present copper deposit at Bornite most likely is Late Cretaceous or Early Tertiary in age, and was derived from a hidden source somewhere south or southwest of the Cosmos Hills. Such a source is especially likely because the copper minerals are in or associated with allochthonous rocks that were thrust into place from the south or southwest.

Reserves

Reliable estimates of copper reserves in the vicinity of Bornite have not been released by the mining companies exploring there in recent years. Although Lund (1961) reported that more than 100 million tons of potential ore averaging better than 1.2% copper had been revealed by drilling during the period 1957-1961, his figures are believed to have been generous.

GOLD

Type and Source

Gold in the Cosmos Hills is confined largely to (1) placer deposits of possible Tertiary age derived mainly from auriferous quartz veins that cut Devonian strata metamorphosed during granite emplacement in Early Cretaceous time, and (2) placer deposits of Pleistocene to Recent age derived from the early placers or from glacial till. A close relationship between gold and granite in the Cosmos Hills is suspected. In this area, the richest placers appear to have been derived, in part, from autochthonous(?) rocks that surround intrusive granite, and free gold reportedly has been observed mainly in quartz veins that cut autochthonous(?) phyllite less than 6 miles from the granite (Riley Creek).

Young quartz veins of possible Late Cretaceous or early Tertiary age also cut allochthonous Devonian and Cretaceous strata in and near the map area, and minor vein quartz cuts serpentinite in at least one place near Shungnak Mountain. However, these veins and the copper-bearing veins mentioned above, which cut Cretaceous strata in the Angayucham Mountains about 25 miles from exposed intrusive granite, are not known to contain appreciable quantities of gold. Furthermore, placer gold apparently is absent or rare in parts of the Cosmos Hills underlain primarily by strata of Cretaceous age. The evidence at hand, therefore, suggests that the gold-bearing quartz veins of this area were emplaced mainly during a late stage of the metamorphism that accompanied granite emplacement in Early Cretaceous time.

Shungnak River and Vicinity

Placer mining along and near the Shungnak River was done intermittently from 1898 at least until 1940, although activity was not very intense from 1915 to 1928. By 1905, four claims were active on the Shungnak River and Dahl Creek, and the Shungnak placers were the largest producers (Brooks, 1906, p 8; 1909, p 59). By 1909, however, production there was surpassed by that of the Dahl Creek placers (Brooks and others, 1910, p 46).

The placer deposits of the Shungnak River and vicinity consist mainly of relatively young gravel deposited on benches as much as 25 feet above the river, plus gravel deposited in the beds of the Shungnak River and Bismark Creek. Much attention has been focused near the mouth of the creek, where it cuts across one of the benches. Auriferous gravel near and downstream from the confluence of the river and creek is as much as 20 feet thick. Gold lies on false bedrock strata above till of Pleistocene (possibly Illinoian) age described by Fernald (1964). The till has been partly eroded and reworked by the river and creek. The local river gradient there is about 25 feet per mile. Most of the gold recovered from that area was very fine-grained, and flour gold predominated along Bismark Creek (Reed, 1932, p 22, 25, 27). Farther upstream near the mouth of the lower canyon of the Shungnak, the gravel is only 1 to 3 feet thick and lies on bedrock, which acted as natural riffles. Some of the gold recovered there, especially on black slate, was coarse and rough and included rusty nuggets weighing as much as 2 3/4 ounces (Brooks, 1909, p 59). The northernmost placer observed along the Shungnak during the recent mapping is on a bench on the east bank of the river between the upper and lower canyons. All of the auriferous gravels of the Shungnak contain numerous boulders as much as 3 feet in diameter, many of which have been derived from till.

Mining methods on the Shungnak have varied. During the early stage, wing dams were used to divert the river for normal shoveling-in and sluicing, but such work commonly was interrupted when the river was high (Brooks, 1909, p 59). Automatic gates were installed in 1915 (Brooks and others, 1916, p 71). Ditches brought water to the higher benches, but shoveling-in there was not very practical (Reed, 1932, p 23). A long ditch that formerly brought water from the upper part of Marble Creek to the northernmost placer still was visible in 1969. From 1928 to 1930, gravels near and south of the mouth of Bismark Creek were drilled and tested for possible dredging, but the use of a dredge could not be justified (Smith and others, 1930, p 44; 1932, p 49; 1933, p 51; Reed, 1932, p 27). Instead, several miles of ditch were dug along the southern flank of the Cosmos Hills, and by 1932 hydraulic mining equipment and a dragline were in use (Smith and others, 1933, p 51; 1934a, p 48; Smith, 1934b, p 53, 54). By 1934, however, the project was abandoned (Smith, 1936, p 55, 56). Subsequent work was limited to small-scale sluicing as late as 1940 (Smith, 1942, p 64).

Total production figures for the Shungnak River placers are not available. However, these placers yielded about 3000 ounces of gold up to 1908 (Brooks, 1909, p 59). Total production may have reached 10,000 ounces, but such a figure must be considered speculative.

Dahl Creek

Two main placer deposits along Dahl Creek were worked intermittently for gold from 1898 to 1961. They are separated by a narrow, boulder-filled canyon, which extends from the SW¼, SE¼, sec. 10, T. 18 N., R. 9 E., to the center of the SW¼ sec. 15. The upper deposit reaches approximately 1 mile from the mouth of the canyon to the north end of an abandoned air strip in sec. 21.

The upper and lower placer deposits occupy different environments of deposition. The upper one is underlain by bedrock, which acted as natural riffles. This deposit occupies the bottom of a large, V-shape, unglaciated (at least unscoured) valley, and is fed by several important tributary streams. The gradient of Dahl Creek in this location is approximately 150 feet per mile. Gold in the placer was concentrated near the base of a strip of gravel a few hundred feet or yards wide but only 5 to 25 feet thick. This gravel may be as old as Tertiary or as young as the benches of probable Pleistocene age found along the Shungnak River. Regardless of its maximum age this gravel has been partly eroded and reworked by Dahl Creek during episodes of high run-off, especially in Pleistocene time. In contrast, the lower placer deposit is underlain by glacial drift of Pleistocene (possible Illinoian) age into which the stream has cut. Gold in the lower placer was found on false bedrock strata commonly less than 10 feet beneath the surface (Smith and Eakin, 1911, p 292-294). Shafts sunk 25 to 80 feet through till penetrated barren gravel and failed to reach bedrock (Reed, 1932, p 31-36). The lower placer deposit does not occupy a large valley and is fed only by Dahl Creek. The local stream gradient there, however, is comparable to that in the upper placer area. The lower placer deposit cannot be older than Pleistocene, and undoubtedly was derived largely, if not entirely, from the upper one.

The upper placer deposit on Dahl Creek was the richest. Gold was most abundant near the mouth of Wye Creek, where the underlying bedrock is phyllite cut by quartz veins 1 inch to 4 feet thick. Most of the gold recovered was fine-grained and angular to subangular, and some was even spongy (Smith and Eakin, 1911, p 293). Wire gold was rare. The angularity and sponginess of the gold indicated that it had not traveled far. Several large nuggets also were found in that area. The biggest was found in 1911 and weighed nearly 3 pounds. It was valued at about $600, with gold worth approximately $16.50 per Troy ounce. Brooks (1912, p 42) described that nugget as a large, thin, subangular slab of gold to which no quartz was attached. Smith and Eakin (idem), however, described a fairly well worn, 4-ounce nugget to which a considerable amount of greasy-looking, milky quartz was attached. The presence of quartz on this nugget and the presence of specks of free gold in quartz veins of the district led to the conclusion that the gold was derived from auriferous quartz veins close to the upper placer deposit on Dahl Creek.

The lower placer deposit was not as rich as the upper one mainly because it is younger and farther from the source. The boulder-filled canyon upstream from this deposit undoubtedly trapped a certain amount of detrital gold, which did not reach the lower placer. In general, the gold found in this placer was fine-grained, somewhat rounded and shot-like, largely because of the greater distance it traveled.

Other metallic minerals of interest found in the Dahl Creek placer concentrates include abundant magnetite, and subordinate chromite and native silver. The magnetite undoubtedly was derived from serpentinite and meta-volcanic rocks in the vicinity of Dahl Creek, which contain abundant accessory magnetite. Smith and Eakin (idem) reported chromite boulders as much as 1 foot in diameter, which most likely were derived from serpentinite. They also described and analyzed nuggets of native silver as much as 1 inch in diameter, the source of which is unknown. The authors emphasized the lack of garnet in the concentrates, which clearly reflects the low metamorphic grade of rocks in the source area.

Mining methods on Dahl Creek have varied. Spasmodic sluicing was done from 1898 to 1906, and systematic mining by sluicing began in 1907 (Brooks and others, 1909, p 59; 1925, p 51). Hydraulic mining was reported during the period 1922-1926 (Brooks and others, 1924, p 49; Smith and others, 1929, p 28). This work was done in the SE¼ sec. 3, T. 18 N., R. 9 E., where hydraulic mining equipment still can be seen. During the period 1927-1940, from 1 to 4 active claims on Dahl Creek were mentioned briefly in U. S. Geological Survey Bulletins concerning the mineral resources of Alaska, but hydraulic mining was not recorded. C. E. Stout (oral communication, 1968) reported that more hydraulic mining was done near the mouth of Wye Creek during the period 1938-1956. During the period 1954-1961, Stout reworked much of the better placer ground on Dahl Creek, and was most successful in the area underlain by phyllite near the mouth of Wye Creek. Numerous piles of gravel stripped by bulldozer at that time now are visible along Dahl Creek. Gold was recovered by sluicing and the use of mercury with copper plates.

Total gold production figures for the Dahl Creek placers have not been published. However, private records suggest that more than 300 ounces of gold per year were produced during certain favorable periods. It is possible that the total production reached 20,000 ounces, but this estimate may be high.

California Creek

A gold-bearing placer deposit was discovered on California Creek in 1918 in a position comparable to that of the upper placer deposit of Dahl Creek. A narrow, boulder-filled canyon, which is cut into garnetiferous greenstone, extends across the eastern half of sec. 21 and the western half of sec. 22, T. 18 N., R. 10 E. The California Creek placer deposit reaches at least 3/4 of a mile from the head of that canyon eastward to the SW¼ sec. 14. This deposit occupies an unglaciated valley fed by several important tributary streams, which drain an area underlain mainly by phyllite and metavolcanic rocks. The phyllite is cut by numerous quartz veins. Gold in the placer deposit presumably was derived from those veins or similar ones removed by erosion. The age of this deposit is believed to be similar to that of the upper placer deposit of Dahl Creek.

The California Creek deposit consists of gravel which is slightly coarser grained than that of the upper placer deposit on Dahl Creek. The coarser grain size is due partly to stream gradient and partly to proximity to resistant metavolcanic rocks. The local gradient of California Creek is approximately 200 feet per mile. The gravel contains numerous boulders as much as several feet in diameter derived from greenstone and greenschist exposed nearby. Gold was found mainly in the lower part of the gravel close to bedrock.

The California Creek placer deposit was mined intermittently from 1918 to 1940 (Cathcart, 1920, p 197; Smith, 1942, p 64). Early mining probably was done by sluicing, but hydraulic mining equipment was installed in 1922 (Brooks and others, 1924, p 49). By 1924, hydraulic mining on California Creek was considered the first large-scale mining operation in the Shungnak district, and by 1926, this operation was the largest producer in the district (Brooks and others, 1925, p 52; Smith and others, 1929, p 28). Flumes, mining equipment, and piles of stripped gravel still can be seen along the creek, but production records are not available. Total production probably did not exceed that of Dahl Creek (Guy Moyer, oral communication, 1968).

Lynx Creek

Small-scale mining of a placer deposit on Lynx Creek was done from 1912 at least until 1940 (Brooks and others, 1913, p 50; Smith, 1942, p 64). This deposit extends from the NE¼ sec. 9 to the southern part of sec. 3, T. 18 N., R. 10 E. The local stream gradient ranges from 240 to 370 feet per mile. The main workings were located where the stream gradient was relatively low in the NE¼ sec. 9 and NW¼ sec. 10. Reed (1932, p 47-48) reported smaller workings in two places in the southern part of sec. 3. The Lynx Creek placer deposit consists of a thin veneer of gravel lying on garnetiferous muscovite schist and related rocks, which are cut by quartz veins. Gold presumably derived from quartz veins was found mainly close to bedrock, which acted as natural riffles. The age of the deposit probably is comparable to or less than that of the upper Dahl Creek placer. Gold was recovered primarily by sluicing. Reed (idem) reported that approximately half of the gold was small nuggets, and the rest was shot-like. No production figures have been published, but the deposit contained enough gold to support a 1- or 2-man mining operation for at least 28 years.

Riley Creek

Detrital gold was mined on a small scale intermittently from 1908 to about 1940 in an unusually high, steep, and dry tributary of Riley Creek approximately 3000 feet northeast of Shield Mountain (Smith and Eakin, 1911, p 294-296; Smith, 1942, p 64). The area mined is about 700 feet long and a few tens of feet wide (Reed, 1932, p 39-40). It is at an elevation of 1400 to 1500 feet where the local stream gradient is approximately 800 feet per mile. This part of the creek contains visible water only during spring run-off and heavy summer rains. As a result, special ditching described by Smith and Eakin (idem) was required to collect enough water for necessarily limited placer mining.

Placered surficial material at Riley Creek consisted of approximately 7 feet of colluvium overlying slaty or phyllitic bedrock, which is interbedded with the predominant dolomitic limestone of the area. Normal waterlaid stream gravel is absent. The colluvium contains numerous erratic boulders of greenstone as much as 2 feet in diameter, which are of Pleistocene (perhaps Illinoian) age. The age of the colluvium, therefore, is believed to be Late Pleistocene to Recent.

Gold recovered from this deposit was mainly fine-grained, sharp, angular, and spongy. Much of it was found in crevices in bedrock. The gold commonly showed small particles of attached quartz, and could not have traveled far from its source. It is believed to have been derived from quartz veins in the immediate vicinity of Shield Mountain. Quartz veins as much as a few feet wide are especially abundant on a ridge of phyllite about 1200 feet south of the placered ground, and free gold reportedly has been found in them (Guy Moyer, oral communication, 1969). Others cut carbonate rocks at the head of the creek. No large nuggets were found in this deposit, but a few small ones reportedly weighed as much as 1/5 ounce. Total gold production is unknown, but probably was small.

Other Creeks

Prospecting has been done on several other creeks in the area, but very little gold has been produced from them. One gold mining camp reportedly was active from 1933 to 1939 on Boulder Creek, which was described only as a tributary of the Kogoluktuk River (Smith, 1934b, p 53). The location of that creek is uncertain. However, shallow shafts are known to have been sunk on Glacier, Radio, and Canyon Creeks, all of which are tributary to the Kogoluktuk, and an old cabin was found on Ryan Creek during the recent mapping. Another camp active in 1933 was on Pearl Creek, which was described only as a tributary of the Shungnak River (Smith, 1934b, p 53). The location of this creek also is uncertain, but it probably was within the area described under the heading Shungnak River above. A little gold was recovered from Jay Creek in an area underlain by phyllite east of Cockscomb Ridge in 1931 (Reed, 1932, p 20, 31), and prospecting apparently was done on Ruby Creek at about the same time. However, till rather than normal placer gravel was found at both places.

Reserves

Gold reserves in the Cosmos Hills are considered low. Favorable placer gravels are rare and of limited extent. The best one, immediately upstream from the Dahl Creek canyon, already has been worked with the aid of modern heavy equipment. In general, stream gradients in the area are too steep and gravels are too young to constitute favorable environments for large concentrations of placer gold. Furthermore, no evidence has been found to indicate the presence of large quantities of lode gold. Although free gold in vein quartz has been reported in the past, none was observed during the recent mapping. Analyses of vein quartz collected by the U. S. Geological Survey near Shield Mountain yielded discouraging results (I. L. Tailleur, oral communication, 1968).

ASBESTOS

History of Mining

In 1944-45, a wartime shortage of asbestos encouraged brief mining of fibrous tremolite and chrysotile from the Ing-Ihk mine at Asbestos Mountain. This mine consisted of several trenches as much as 200 feet long and a 228-foot adit, which was connected to one of the trenches by a 60-foot raise or shaft (Heide, Wright, and Rutledge, 1949, p 2). Total production included about 36.5 tons of tremolite suitable for filters and 1 ton of chrysotile (idem, p 6, 12). During the same period, the U. S. Bureau of Mines conducted bulk sampling of asbestos-bearing serpentinite south of Bismark Mountain and west of Cosmos Creek. In 1946, this work was extended to include cleaning, enlarging, and sampling of some of the workings at Asbestos Mountain. Samples weighing ½ to 2 tons were shipped to the USBM laboratory at Rolla, Missouri, and to the Johns-Mansville laboratory at Asbestos, Quebec, for thorough testing, but no more asbestos was mined. The main sample sites and mine workings were described and mapped in detail by Heide, Wright, and Rutledge (1949, figs 6-11). They are shown in serpentinite units on the present geologic map (*fig 4*).

Deposits

The local asbestos deposits include both slip-fiber and cross-fiber types, and normally contain either tremolite or chrysotile. In the slip-fiber deposits, fibrous asbestiform crystals tend to be oriented parallel or nearly parallel to the walls of veinlets, slickensided joints, or small shear zones. In the cross-fiber type, the crystals tend to be more nearly perpendicular to the enclosing walls. Slip-fiber tremolite predominates, with crystals commonly only a few inches long. At Asbestos Mountain, Heide, Wright, and Rutledge (1949, p 9, 12) described seams and vein-like deposits of slip-fiber tremolite and chrysotile as much as 6 and 4 inches wide, respectively, but both minerals formed rare fibers as much as 20 inches long. In contrast, most of the cross-fiber veinlets observed in the course of bulk sampling were less than ½ inch wide (idem, p 8).

Both kinds of deposit were emplaced during a late stage of the hydrothermal activity responsible for serpentinization. Deposition of the slip-fiber type apparently accompanied final shearing of the serpentinite. Relatively unsheared cross-fiber veinlets that cut sheared rocks obviously represent a final stage of the hydrothermal activity.

Testing and Potential

Testing of the Cosmos Hills asbestos by and for the U. S. Bureau of Mines included the use of dryers, cone crushers, impact mills, and various kinds of screen (Heide, Wright, and Rutledge, 1949, figs 13-16). In comparison with Canadian asbestos, this material is characterized by (1) an unusually high dust or fines content, (2) a high loose density, (3) a short staple length, determined by the wet screening method, and (4) a fast rate of filterability (idem, p 20). Long fibers are strong, but closely matted. They lack the silkiness of Canadian fibers, and are difficult to separate. Recovery of high-grade material was so low that the deposits of this area are not considered a good source of spinnable asbestos. On the other hand, the high filterability of medium-length fibers makes them suitable for the manufacture of shingles and other asbestos-cement products, in addition to filters (idem, p 24, 25). In summary, the remote location, small thickness, and sheared condition of most of the serpentinite host rocks in this area, as well as the small quantity of recoverable asbestos, make it unlikely that large-scale asbestos mining ever will be undertaken here.

JADE

Two varieties of jade exist in nature, but only one has been found in western Arctic Alaska. Jadeite, a variety of pyroxene, is a sodium-aluminum silicate apparently foreign to this region. Nephrite, a variety of amphibole, is a calcium-magnesium-iron silicate associated with serpentinite in the Cosmos Hills and Jade Mountains. Four samples of nephrite collected from Jade Mountain by Cantwell (1884, p 57-60) were analyzed by Clarke and Merrill (1888), and their analyses were republished by Smith (1913, p 155) and Smith and Mertie (1930, p 345).

Nephrite actually is compact, fine-grained tremolite or actinolite. Thus its color varies from nearly white to dark green, and fine-grained green antigorite or serpentinite in this area is easily misidentified as jade. In general, the two materials are distinguished from one another by hardness, crystal habit, and percentage of inclusions. The serpentinite is softer and tends to contain more abundant, disseminated, dusty, black magnetite. Antigorite characteristic of the serpentinite is platy, but individual crystals commonly are too fine-grained to be recognized by the naked eye. Nephrite, on the other hand, may show chatoyance due to the prismatic or acicular habit of tremolite-actinolite, especially in cross-fiber veinlets that cut serpentinite. A photograph of an unusual necklace of chatoyant nephrite from the Cosmos Hills recently was published in a lapidary journal (Leiper, 1969, p 52).

Since 1958, green boulders derived from serpentinite have been recovered from old placer tailings along Dahl Creek for sale as jade. Claims also have been staked on Cosmos and California Creeks and in several places near the Shungnak River. The green boulders recovered from streams in this area are as much as several feet in diameter. Their compositions and textures vary markedly. Some definitely contain nephrite, but others are composed largely of antigorite. In 1969, for example, four samples of possible jade from Dahl Creek were analyzed by X-ray diffraction for local prospectors, and three of the samples turned out to be mainly antigorite (serpentinite) rather than nephrite (jade). This does not mean that Dahl Creek jade is necessarily inferior to any other, but it emphasizes the difficulty in identifying the preferred material. Of all the streams in the area, Dahl Creek probably contains some of the best jade, because much of the serpentinite source rock near Asbestos Mountain is less sheared than serpentinite found closer to overthrust faults elsewhere. However, much of the jade from the Cosmos Hills is highly fractured, because the serpentinite with which it is associated has been involved in strong tectonic activity. Furthermore, the rocks have been subjected to severe frost action, which tends to enlarge previous fractures.

In 1969, jade was being recovered from both the upper and lower placer areas on Dahl Creek, and a little work was being done farther west. At Dahl Creek, boulders were moved with the aid of a small bulldozer and tractor. The rocks were cut with diamond saws in the field to facilitate handling and to determine their internal composition, texture, and color. Highly sheared and fractured rock is undesirable, because it will not remain intact during grinding and polishing. Small seams and layers of relatively unsheared material, however, can be used to make cabochons. This is the ultimate use of most of the local jade, but large relatively unsheared samples of either jade or serpentinite can be used for other lapidary products such as bookends, pen holders, and carvings. Completely unsheared or unfractured material is rare, but some specimens from Dahl Creek observed by the writer contain beautifully banded, relatively unsheared zones several inches wide that are highly prized. The current price of the local jade in the field is $1 or more per pound, depending upon the quality of the material and the quantity available.

GEOCHEMISTRY

Geochemical work involved the collection and analyses of 124 samples from the Shungnak D-2 quadrangle in 1968 and 112 samples mainly from the Ambler River quadrangle in 1969. A few sampled collected in 1969 were from the head of Canyon Creek in the Shungnak quadrangle. The distribution of all sample sites, which are numbered consecutively, is shown on figure 3. Analyses for copper, lead, and zinc were done by the atomic absorption method. Analyses for 30 elements, including those metals, were done by the emission-spectrograph method. Samples collected in 1968 were analyzed by the U. S. Geological Survey in Anchorage, Alaska. Samples collected in 1969 were analyzed by the Division of Mines and Geology and by the University of Alaska Mineral Industries Research Laboratory in College, Alaska. Analyses and analysts are listed on table 1 of ADMG Geologic Report 37 and on table 1 of the present report. Intervals of estimation and detection limits for semiquantitative spectrographic analyses are listed in table 2.

Most samples were stream sediments collected beneath running water, but a few were soil samples from relatively dry valleys. Both years were unusually dry for this part of Alaska. Sampling was confined mainly to valleys where bedrock is close to the present land surface. Surficial materials in these valleys presumably were derived mainly or entirely from nearby bedrock. A few samples, however, were collected along the Shungnak River for comparison. The relatively low metal content of the Shungnak samples reflects the fact that surficial materials along that river include abundant glacial debris derived from the Brooks Range north of the Cosmos Hills.

At the request of mining companies currently exploring in the Cosmos Hills, detailed geochemical sampling was not done on their claims within the main copper-bearing areas at and near Bornite. However, samples collected downstream from claims staked on copper-bearing rocks exposed at Pardners Hill give some indication of the quantity of copper that prospectors might expect to find in stream-sediment samples collected in other favorable environments along the southern flank of the Brooks Range.

For convenience in interpretation, the geochemical analyses are tabulated by stream valley and are accompanied by brief statements concerning local bedrock known or inferred to underlie each corresponding drainage basin. Sample populations in the individual valleys are too small for normal statistical analysis, which therefore is not attempted in this report. Only the metals of greatest interest are discussed below.

COPPER, LEAD, AND ZINC

With regard to copper and zinc, the tabulated data show generally good agreement between the two analytical methods on a group basis, but not necessarily on an individual sample basis. This is to be expected, because different portions of the same sample are consumed in each of the two analyses of a given sample. Groups of samples from Cosmos Creek, for example, show high copper values by both methods. However, two samples that gave values of 500 ppm copper by spectrographic analysis yielded values of only 350 and 420 ppm copper by the atomic absorption method. These are the highest copper values obtained in the Cosmos Hills during the recent geochemical sampling, and they clearly reflect the presence of copper in the source area drained by Cosmos Creek. The atomic absorption analyses of samples from the same creek also show moderately high values of 100 to 160 ppm zinc, which undoubtedly reflects the presence of this metal in the source area. Macroscopic chalcopyrite, malachite, azurite, and sphalerite all have been observed by the writer at Pardners Hill. A maximum value of only 50 ppm lead in the same suite of samples reflects the relative absence or scarcity of galena in the source area, and none was observed there by the writer. Moderate copper values of 100 to 135 ppm obtained in samples from streams such as Cascade and Harry Creeks reflect the presence of abundant greenstone, which is characterized by a background copper content higher than that of other rocks in the area such as phyllite or nonmineralized carbonate strata. Moderately high values for zinc without corresponding high values for copper were obtained from several streams such as Aurora, Dahl, Ryan, and Canyon Creeks. This reflects the fact that minor sphalerite is one of the most ubiquitous sulfides in the district, especially in carbonate rocks, and it also is known to be present in certain quartz veins.

COBALT, CHROMIUM, AND NICKEL

Cobalt, chromium, and nickel values all are highest in sediments collected from streams known to drain parts of the area where serpentinite is abundant. High values of 100 to 200 ppm cobalt, 5000 to 10,000 ppm chromium, and 1000 to 2000 ppm nickel were obtained from samples collected along Alder and Serpentine Creeks at the western end of the Cosmos Hills. Highly sheared serpentinite bodies contribute abundant float to those stream valleys. High values for these elements also were obtained from soil samples collected in the vicinity of a small serpentinite body exposed in a relatively dry, unnamed valley south southeast of Inerevuk Mountain. Values of 1000 ppm were obtained from samples collected along Cascade Creek, where massive greenstone is abundant. This suggests that the greenstone might contain higher than normal concentrations of chromium or that unexposed serpentinite is present in that stream valley. Veins containing chromium-bearing muscovite crop out along the north-trending ridge crest north of Black Rock Ridge.

ANTIMONY

Antimony also appears to be most abundant in Alder and Serpentine Creeks, and may be related to the serpentinite exposed near the heads of those creeks. Stibnite is not known to be present in the Cosmos Hills.

CONCLUSIONS AND GUIDES TO PROSPECTING

1. Detailed geologic mapping in the Cosmos Hills has shown that the Shungnak mining district is restricted to the immediate vicinity of a single major geologic structure now called the Cosmos Hills window. This structure is far more complex than the domelike fold previously inferred there, and probably is even more complex than the present geologic map indicates. The window is framed by parts of at least three sheets of allochthonous Devonian strata and an uppermost sheet of allochthonous Cretaceous strata. Each sheet has moved at least several miles, and the cumulative displacement undoubtedly exceeded 20 miles.

2. The geologic history of bedrock in the district includes (1) marine sedimentation and volcanism in Devonian time, including the deposition of more than 2000 feet of fossiliferous dolomitic limestone of Middle Devonian age, (2) vigorous orogenic activity in Cretaceous time, including granite emplacment, doming, metamorphism, emplacement of auriferous quartz veins, and overthrust faulting of Devonian strata, (3) continued or renewed tectonic activity in latest Cretaceous or Early Tertiary time, including overthrust faulting of Cretaceous strata, contemporaneous emplacement and serpentinization of ultramafic rocks along and near the uppermost overthrust fault, and widespread hydrothermal activity related to the serpentinization, and (4) high-angle faulting in Tertiary time.

3. No indisputable evidence has been found to confirm the Jurassic(?) age formerly assigned to metavolcanic rocks characteristic of the Cosmos Hills and mountains immediately east of this area. Although paleontological studies have not been completed, preliminary paleontological evidence suggests a probable Devonian, possible Middle Devonian, age for these rocks and related carbonate strata.

4. The copper deposit at Bornite appears to be structurally as well as stratigraphically and lithologically controlled. Evidence available at the present time suggests that the deposit is epigenetic rather than syngenetic in origin. Copper minerals are most abundant where dolomite breccia is close to and oblique to an underlying overthrust fault on the north flank of a gentle antiform. The antiform consists of arched imbricate thrust plates that have moved across a previously block-faulted anticline and dome. The fault beneath the copper deposit is the lowermost of four overthrust faults mentioned above, but the host rocks probably were also intersected by the uppermost thrust before erosion produced the present topography (*cross sections D, E, F, and G, fig 4B*). In the opinion of the writer, the copper deposit most likely assumed its present form and position during widespread hydrothermal activity associated with serpentinization of ultramafic rocks emplaced along and near the uppermost overthrust fault in latest Cretaceous or Early Tertiary time.

5. Geologic maps of the Kobuk trough suggest that the clastic Cretaceous strata characteristic of the northern part of that trough are in overthrust fault contact with underlying rocks both east and west of the Cosmos Hills. Other copper sulfide deposits may exist along or near this important tectonic boundary. Fragmental carbonate rocks of Devonian age north of this boundary should be considered possible favorable sites for copper mineralization, especially where they are intersected by overthrust faults. Brecciated metavolcanic rocks also might be favorable hosts, although agglomerate adjacent to the uppermost thrust near the head of California Creek does not appear to have been mineralized. Imbricate overthrust faults can be anticipated in exploration along the entire southern flank of the Brooks Range.

6. The Cosmos Hills are not considered a favorable site for large-scale gold exploration and mining. The richest and oldest (Tertiary? to Pleistocene) placer above the Dahl Creek canyon has been worked out. Others in the district either are too young (Pleistocene to Recent) or are characterized by stream gradients that are too steep (200-800 feet per mile) to constitute likely sites for large concentrations of placer gold. If lode gold deposits exist in the district, they probably will be found in areas underlain mainly by phyllite or schist of Devonian age cut by quartz veins of Early Cretaceous age related to intrusive granite. Quartz veins that cut allochthonous strata of Cretaceous age, which have been thrust over the granite and Devonian rocks, are not known to contain appreciable quantities of gold.

7. The Shungnak district will continue to be a favorable site for the recovery of the nephrite variety of jade, although many of the serpentinite source rocks in the area are highly sheared. Thin serpentinite bodies near the uppermost overthrust fault probably are the least favorable for prospecting. Serpentinite of the Cosmos Hills does not constitute a potential source of commercial asbestos, nickel, chromium, or cobalt in the near future.

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