

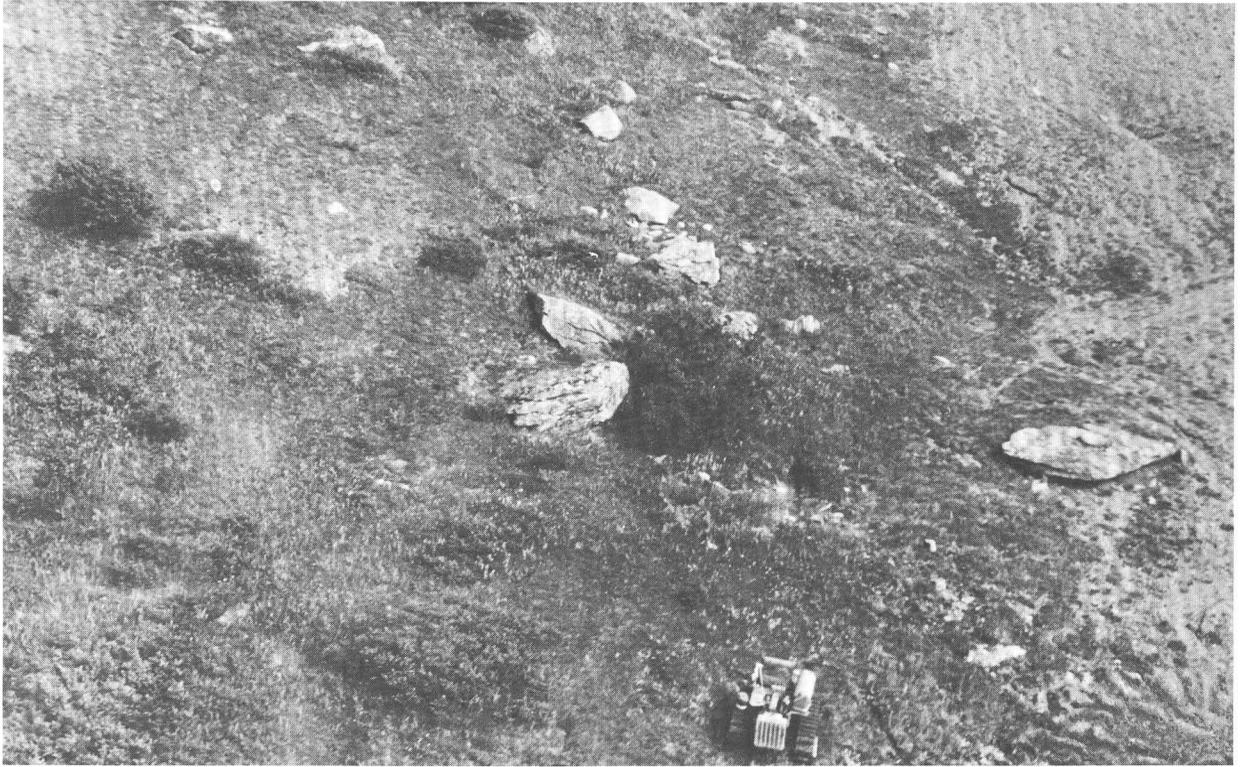
GEOLOGICAL SURVEY CIRCULAR 793



The Alaskan Mineral Resource Assessment
Program: Background Information to
Accompany Folio of Geologic and Mineral
Resource Maps of the Ambler River
Quadrangle, Alaska

*Prepared in cooperation with the State of Alaska
Department of Natural Resources, Division of
Geological and Geophysical Surveys*

THE ALASKAN MINERAL RESOURCE
ASSESSMENT PROGRAM



Large boulders of nephrite (jade) which have weathered from serpentinite at the jade prospect on south side of the Jade Mountains. (Photo by I. L. Tailleux, 1972)



Exploratory development at the Arctic copper-zinc-lead-silver deposit on the ridge divide between the Kogoluktuk and Shungnak Rivers. (Photo by I. L. Tailleux, 1972)

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By C. F. Mayfield, I. L. Tailleux, N. R. D. Albert,
Inyo Ellersieck, Donald Grybeck, and S. W. Hackett

G E O L O G I C A L S U R V E Y C I R C U L A R 7 9 3

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Department of Natural Resources, Division of
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United States Department of the Interior
JAMES G. WATT, *Secretary*



Geological Survey
Dallas L. Peck, *Director*

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The Alaskan Mineral Resource Assessment Program: Background Information to Accompany Folio of Geologic and Mineral Resource Maps of the Ambler River Quadrangle, Alaska

By C. F. Mayfield, I. L. Tailleux, N. R. D. Albert, Inyo Ellersieck, Donald Grybeck, and S. W. Hackett¹

ABSTRACT

The Ambler River quadrangle, consisting of 14,290 km² (5,520 mi²) in northwest Alaska, was investigated by an interdisciplinary research team for the purpose of assessing the mineral resource potential of the quadrangle. This report provides background information for a folio of maps on the geology, reconnaissance geochemistry, aeromagnetism, Landsat imagery, and mineral resource evaluation of the quadrangle. A summary of the geologic history, radiometric dates, and fossil localities and a comprehensive bibliography are also included. The quadrangle contains jade reserves, now being mined, and potentially significant resources of copper, zinc, lead, and silver.

INTRODUCTION

PURPOSE AND SCOPE

This circular and a separately available folio of maps constitute a compilation and assessment of the mineral resources of the Ambler River quadrangle, Brooks Range, Alaska, prepared under the auspices of the Alaskan Mineral Resource Assessment Program (AMRAP). The purpose of AMRAP is to provide basic information which will help Federal, State, and local agencies and industry formulate mineral resource policies and provide a basis for making local land-use planning decisions. AMRAP also intends to update existing mineral resource compilations, to help stimulate private resource development, and to increase understanding of the geology of Alaska.

The 11 maps in the folio of the Ambler River quadrangle mineral resource assessment are listed in table 1. The folio is an integration of the geology, geochemistry, geophysics, telegeology, and mineral occurrences into a series of reports that summarize the currently known mineral resource potential of the quadrangle. It represents the efforts of an interdisciplinary team of geoscientists, each contributing knowledge in his field of specialty to the resource assessment.

This circular is designed to not only draw attention to the folio of mineral assessment maps but also to provide background information relevant to understanding what is known about the complex geology of the quadrangle. New information that has become available since the publication of the maps in the folio is also presented. The circular includes a brief history of mineral exploration and production, a summary of the geology, and description of the regional metamorphism, and a compilation of rock ages based on radiometric dates and fossil localities. This is followed by a short description of each component map in the folio. In addition, the circular contains a comprehensive geologic bibliography of the Ambler River quadrangle.

GEOGRAPHY AND ACCESS

The Ambler River quadrangle covers approximately 14,290 km² (5,520 mi²) in northwestern Alaska (fig. 1) between 67° and 68° N. latitude and 156° and 159° W. longitude. An addition of part of the Shungnak quadrangle to the southeast corner of the Ambler River quadrangle has been included in the folio resource assessment maps to show the

¹Alaska Division of Geological and Geophysical Surveys, Fairbanks, Alaska 99701.

TABLE 1.—Component maps of the Ambler River quadrangle mineral resource assessment

U.S. Geological Survey Open-File (OF) Reports	Subject
OF 78-120-A (Mayfield and Tailleir, 1978) -----	Geology.
OF 78-120-B (Ellaersieck, 1978f) -----	Stream-sediment geochemical sample locations.
OF 78-120-C (Ellaersieck, 1978a) -----	Analytical results for stream-sediment samples.
OF 78-120-D (Ellaersieck, 1978e) -----	Lead and zinc geochemical anomalies.
OF 78-120-E (Ellaersieck, 1978d) -----	Copper and molybdenum geochemical anomalies.
OF 78-120-F (Ellaersieck, 1978g) -----	Tin and beryllium geochemical anomalies.
OF 78-120-G (Ellaersieck, 1978b) -----	Barium, silver, and arsenic geochemical anomalies.
OF 78-120-H (Ellaersieck, 1978c) -----	Chromium, nickel, and cobalt geochemical anomalies.
OF 78-120-I (Mayfield and Grybeck, 1978) -----	Mineral occurrences and resources.
OF 78-120-J (Albert, 1978) -----	Interpretation of satellite imagery.
OF 78-120-K (Hackett, 1980) -----	Aeromagnetic map and interpretation.

entire geology of the Cosmos Hills. The Baird and Schwatka Mountains of the southwest Brooks Range trend in a west-northwesterly direction through the central part of the area. Streams in the south half of the quadrangle flow into the Kobuk River, and in the north half, they flow into

the Noatak River. Elevations range from 30 m (100 ft) along the lower Kobuk River in the southwest to just over 1970 m (6,000 ft) in the Schwatka Mountains in the east-central part of the quadrangle. Most of the mountains rise to 1,000–1,300 m (3,000–4,000 ft) and intervening valleys from about 160 to 650 m (500 to 2,000 ft). The area has undergone multiple stages of glaciation in the Pleistocene which formed the broad U-shaped valleys that contain most of the larger streams in the mountains (Fernald, 1964). Remnants of these glaciers are visible as small stagnant ice fields in a few of the north-facing cirques in the east-central part of the quadrangle.

The Ambler River quadrangle is situated in the back country of Alaska. There are no roads leading into the area, and the most feasible access is by airplane. There are three improved dirt airstrips. One is located at the village of Ambler on the Kobuk River, and the other two are in the Cosmos Hills at the mining camp of Bornite on Ruby Creek and near Dahl Creek. As a result, access to most other areas is by helicopter or by light plane which must land on gravel bars or small lakes. The distance to the nearest supply centers are Kotzebue, 230 km; Bettles, 260 km; and Fairbanks, 530 km. Access can also be gained to the quadrangle by small boat on the Kobuk or Noatak Rivers. Larger items can be brought into the area by barge from Kotzebue during the summer months if the Kobuk River is high enough. There is a dirt road between the village of Kobuk on the Kobuk River and the mining camp of Bornite in the Cosmos Hills.

The only permanent town in the quadrangle is Ambler, with a population about 200, located at the confluence of the Kobuk and Ambler Rivers. The mining camps of Bornite, in the Cosmos Hills, and Arctic Camp, on a tributary of the Ambler River, have a seasonal fluctuation in population from caretaker status in the winter up to several dozen people in the summer. Except for irregularly occupied cabins strung out along the Kobuk River and transitory mining exploration camps in the southeastern part of the quadrangle, the remainder of the area is infrequently occupied or visited.

Acknowledgments.—The Ambler River AMRAP project is a combined effort between geoscientists from the Alaska Division of Geological and Geophysical Surveys (ADGGS) and the U.S. Geological Survey. Appreciation is given to G. H. Pessel, R. E. Garland, G. R. Eakins, and M. A. Wiltse of

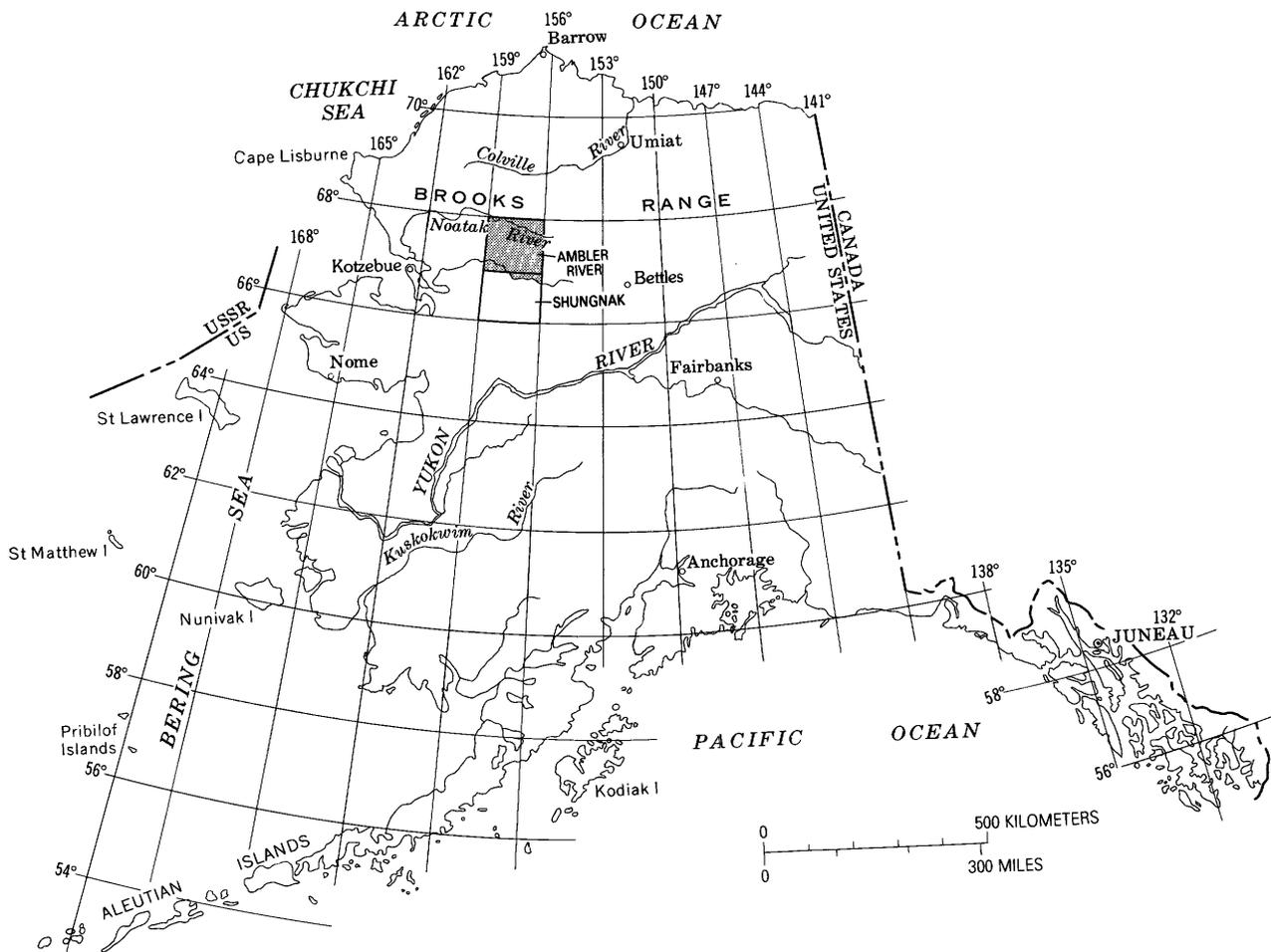


FIGURE 1.—Index map of Alaska showing the location of the Ambler River quadrangle and the northeastern part of the Shungnak quadrangle. Area of report is shaded.

the ADGGS and W. P. Brosgé of the U.S. Geological Survey who helped conduct the early phases of investigation but did not take a direct role in the compilation of this circular or the folio of mineral assessment maps. These geologists have graciously made available field notes, rock samples, thin sections, and mineral occurrence localities as well as provided us with helpful concepts relating to the general geology of the quadrangle. Other scientists, who visited the area and helped with geologic mapping, petrography, and age dating, are W. B. Hamilton of the U.S. Geological Survey, W. G. Gilbert of the ADGGS, and R. B. Forbes, J. R. Carden, and D. L. Turner of the University of Alaska Geophysical Institute.

The work was greatly facilitated by the help of local citizens or other workers engaged in various aspects of exploring the country. The cooperation of many people engaged in minerals exploration,

particularly H. A. Sichermann, R. H. W. Chadwick, N. L. Lutz, R. C. Babcock Jr., and Richard Walters (all formerly with Bear Creek Mining Company) is appreciated. They shared their ideas and contributed logistical support when needed. Tommy Douglas, from Ambler, and John Moyer, from Kobuk, provided helpful information on mineral occurrences and past mining history. Data on some mineral prospects come from the following exploration companies: Anaconda Mining Company, Bear Creek Mining Company, Noranda Exploration, and WGM Inc. Also Buck Maxson of Maxson's Aviation was of great help in giving competent and reliable supply by bush plane to a remote field camp on the Noatak River. Office and laboratory personnel giving much needed assistance include T. C. Tribble of the State of Alaska Mineral Analysis and Research Laboratory and R. M. O'Leary, S. K. McDanal, and C. M.

McDougal of the U.S. Geological Survey for providing chemical analyses and computer compilations of the geochemical sampling data.

SUMMARY OF MINERAL EXPLORATION AND PRODUCTION

Gold has been the principal commodity produced from the quadrangle. The first discoveries are believed to have been made in the Cosmos Hills in 1898 or 1899 which led to a small gold rush about 1900. Most gold was produced between 1900 and 1940 with peak production from 1910 to 1920 from placers located on Dahl Creek, California Creek, and the Shungnak River. Placer operations continued on a smaller scale to the early 1960's; in recent years placer claims have been largely inactive. The total amount of gold produced is estimated to be between 466 and 1244 kg (15,000 and 40,000 oz) almost entirely mined from placers in the Cosmos Hills.

During the gold rush, copper prospects were discovered at Pardners Hill and Ruby Creek in the Cosmos Hills, where a small amount of trenching and tunneling was done. In 1948, interest in the properties was revived when airborne surveys showed a radiometric anomaly associated with the old copper prospect at Ruby Creek. Rhinehart Berg prospected the anomaly by bulldozing, trenching, and a small amount of drilling which uncovered enough mineralized ground to interest Bear Creek Mining Company into conducting a systematic drilling program in 1958 and 1959. This program resulted in the discovery of significant quantities of high-grade copper ore in carbonate breccia. A more complete history of the exploration of the Ruby Creek deposit is reported by Fritts (1970). The discovery at Ruby Creek encouraged the Bear Creek Mining Company to conduct geochemical exploration in the mountains north of the Cosmos Hills. This exploration, in the mid 1960's, resulted in the discovery of several volcanogenic deposits of which the Arctic deposit has the largest known reserves. In recent years, exploration by several mining companies has resulted in the discoveries of several additional volcanogenic deposits. Mining and development of these deposits beyond the initial assessment stage have not yet begun.

Occurrences of asbestos minerals have been known from several localities on the south edge of

the Brooks Range since the gold rush. The only attempt at mining any of these prospects was at the Ing-Ihk mine in the Cosmos Hills in 1944-1945 (Coats, 1944; Heide and others, 1949). The operation was discontinued soon after a 47-ton test shipment of high-grade ore was made.

Jade from deposits in the Jade Mountains and Cosmos Hills had been collected and traded by the Eskimos long before white men ventured into the Arctic. These are the largest known deposits in Alaska. Since World War II, jade mining has supported one- and two-man summer operations in the Jade Mountains and Cosmos Hills. Although production estimates have never been reported, reserves at these locations are expected to keep small operations in business for many years. The deposits presently supply most of the commercial jade mined in Alaska.

GEOLOGIC INVESTIGATIONS

PREVIOUS GEOLOGIC AND MINERAL RESOURCE INVESTIGATIONS

The first exploration of the central Kobuk Valley was made in 1884 and 1885 by two separate parties under different auspices. The first was led by J. C. Cantwell of the U.S. Revenue Marine Service (Cantwell, 1889; McLenegan, 1889), and the second was led by Lt. G. M. Stoney of the U.S. Navy (Stoney, 1900). Stoney's party wintered over at a camp on the Kobuk River south of the Cosmos Hills from which exploration was made into the nearby mountains and Noatak valley. The first recorded exploration into the Noatak valley was in 1885 by S. B. McLenegan of the U.S. Revenue Marine Service (McLenegan, 1887). When gold was discovered in the Cosmos Hills in 1898 or 1899, many prospectors ventured into this unknown territory. A prospector's account of the early conditions in 1898 is given by Grinnell (1901). The first expedition into the area by the U.S. Geological Survey was led by W. C. Mendenhall, who descended the Kobuk River and mapped the geology along the river at a scale of approximately 1:1,250,000 (Mendelhall, 1902). The first mineral investigation was conducted by P. S. Smith during traverses of the Kobuk and Noatak valleys in 1910 and 1911 (Smith, 1913; Smith and Eakin, 1911). In 1931, Irving Reed wrote a brief description of the placer mining operations in the

Cosmos Hills (Reed, 1931). Many other reports of the Alaska mining industry cover the estimated yearly gold production from the period 1904 to 1942. The most notable of these reports, by A. H. Brooks and by P. S. Smith, have been published as a series of *U.S. Geological Survey Bulletins* listed in the bibliography at the end of this report. A systematic compilation of mineral occurrences in the northwestern Brooks Range was made by Eskil Anderson during World War II (Anderson, 1945; 1947). At the end of the war, the asbestos deposits in the Cosmos Hills and Jade Mountains were evaluated by the U.S. Bureau of Mines (Heide and others, 1949) and the U.S. Geological Survey (Coats, 1944).

Post-World War II studies by the U.S. Geological Survey included geologic reconnaissance of the Ambler River and adjacent quadrangles by I. L. Tailleir in 1955, 1958, and 1965. He compiled a large-scale geologic map of the Cosmos Hills and smaller scale maps of the mountains to the north; these maps are unpublished but have provided a basic framework for later geologic maps and studies in the quadrangle. In 1965 and 1966, the southern part of the quadrangle was investigated by Tailleir, W. W. Patton, Jr., and T. P. Miller, and they compiled a 1:250,000 scale geology map of the region (Patton and others, 1968). Additional reconnaissance mapping of the north and central parts of the quadrangle was carried out by Tailleir, W. P. Brosgé, and H. N. Reiser during 1966 (Brosgé and others, 1967). The observed relations between Paleozoic clastic and carbonate units contributed significantly to an understanding of the stratigraphy and restored depositional settings of the Endicott and Baird Groups (Tailleur and others, 1967). Detailed aspects of the geology of the copper deposit on Ruby Creek are given in a Ph.D. dissertation and subsequent publications by D. D. Runnells (1963, 1964, 1965, 1966, and 1969). Other prospect examinations were made by various government agencies and mining companies during the 1950's, 1960's, and 1970's. Because most of these reports are unpublished, they are not readily available. The reports that have been brought to our attention are included in the bibliography of this report.

In 1968 and 1969, C. E. Fritts of the Alaska Division of Mines and Geology completed a project of detailed geologic mapping and geochemical sampling in the Cosmos Hills (Fritts, 1969a, b; 1970). In 1971, Fritts began a similar project in the

southern part of the Schwatka Mountains which continued until his untimely death in a canoeing accident on the Kogoluktuk River in 1972. G. H. Pessel, R. E. Garland, and G. R. Eakins resumed the field operations in the same year and requested Tailleir's assistance. This is the year the current project began, and it continues with the publication of this circular as a cooperative effort between the Alaska Division of Geological and Geophysical Surveys and U.S. Geological Survey.

PRESENT STUDY

Most of the field and laboratory work closely related to this study was begun in 1972 by Pessel, Garland, and Eakins of the ADGGS and Tailleir of the U.S. Geological Survey. These workers released stream-sediment geochemical analyses (Garland and Pessel, 1975) and a geologic map of the southeastern part of the quadrangle at 1:63,360 scale (Pessel and others, 1973). In 1973 and 1974, Pessel and Tailleir were joined by Brosgé of the U.S. Geological Survey, and the project was expanded in the mountains of the south-central and southwestern part of the quadrangle. Stream-sediment geochemical analyses from this part of the area were released by Garland and others (1975) and Pessel (1976). Detailed mapping and study of selected volcanogenic deposits were carried out by M. A. Wiltse (1975). Gilbert and others (1977) completed a geologic and geophysical cross-section in the Ruby Ridge area of the metamorphic terrane which contains the volcanogenic deposits. A preliminary geologic map at 1:250,000 scale was compiled by Pessel and Brosgé (1977) from fieldwork of the years 1955-1966 and 1972-1974). Geologic mapping and geochemical sampling in the north half of the quadrangle were concluded in 1976 by Tailleir, Mayfield, and Ellersieck. An aeromagnetic survey was flown in the western and eastern parts of the quadrangle in 1974 and 1975 under contract to the ADGGS. The resulting aeromagnetic contour maps were released by S. W. Hackett (1977). Landsat imagery was analyzed in 1978 by N. R. D. Albert. Although many of the above-mentioned geologists did not take an active role in the mineral resource assessment of the Ambler River quadrangle, their published reports as well as rock samples, field notes, and informal discussions constitute a valuable contribution to this report and to the mineral assessment maps.

GEOLOGY OF THE AMBLER RIVER QUADRANGLE

GEOLOGIC TERRANES

Rocks in the Ambler River quadrangle are here broadly divided into five terranes on the basis of age and lithologic association. These geologic subdivisions are: the Kobuk River terrane, the Jade Mountains-Angayucham Mountains terrane, the schist belt terrane, the Schwatka Mountains terrane, and the Endicott Mountains terrane (fig. 2).

The Kobuk River terrane is located along the south edge of the quadrangle where it consists of the rocks of the Kobuk valley and southern foothills of the Brooks Range. Most of the area is covered by forest or tundra growing on a veneer of unconsolidated alluvial and glacial deposits. Bedrock, exposed discontinuously in stream cuts or hilltops, consists of folded and faulted Early Cretaceous sedimentary rocks which are the youngest rocks in the quadrangle. These rocks mostly consist of micaceous quartz conglomerate and lesser interbedded sandstone and mudstone that have a few thin coal seams visible in stream cuts along the lower Ambler River. Induration of the rocks appears to increase toward the north and is greatest in the sedimentary strata flanking the Cosmos Hills where, in some places, conglomerate clasts appear to be tectonically stretched. Bedrock in this terrane generally dips south and unconformably onlaps rocks of the Jade Mountains-Angayucham Mountains terrane to the north.

The Jade Mountains-Angayucham Mountains terrane, located along the south flank of the Brooks Range, consists of a relatively narrow belt of mafic and ultramafic rocks with minor chert, fine-grained clastic rocks, and reef carbonate rocks. Mafic rocks are mostly diabase and basalt with local pillow structures and may be of several different ages. In some places, where they were most highly recrystallized by regional metamorphism, they have been transformed to fine-grained chlorite-albite schist. In the Angayucham Mountains the rocks are not strongly metamorphosed, and bedded chert, correlative with Triassic chert east of the quadrangle (Plafker and others, 1978), is locally found associated with the basalts. Ultramafic rocks consist of discontinuous serpentinites in the Cosmos Hills and Angayucham Mountains and serpentinitized dunite or peridotite in the Jade Mountains and near the Hunt River. In the Jade Mountains, peridotite or dunite rests upon diabase

or basalt with a probable fault contact. In many places, serpentinite was probably squeezed into shear zones(?) in either mafic or carbonate and shale sequences. Paleozoic limestone and dolomite and intercalated phyllite occur structurally below most mafic-ultramafic rocks. However, in the breached antiform that is exposed in the Cosmos Hills, middle Paleozoic carbonate rocks may have been locally intruded by mafic igneous rocks or may have been deposited contemporaneously with mafic volcanic rocks (Fritts, 1970). Carbonate rocks are more than 200 m thick in some places in the Cosmos Hills and Jade Mountains and completely absent or thin and discontinuous in other places. Except for north-dipping beds along the north side of the Cosmos Hills antiform, rocks of this terrane dip south away from the Brooks Range. In most exposures, ultramafic rocks overlie mafic rocks which in turn overlie carbonate rocks and phyllite. This west-trending belt of mafic and ultramafic rocks flanking the mountains may represent a late Mesozoic plate boundary between what is now the Yukon-Koyukuk Province to the south and the Brooks Range to the north (Tailleur, 1973; Patton and others, 1978; Roeder and Mull, 1978).

The schist belt terrane is a thick accumulation of metamorphosed sedimentary rocks constituting the south half of the Baird and Schwatka Mountains. Most rocks are gray phyllite or quartz-mica schist thought to have been a thick pile of predominantly pelitic clastic rocks prior to being metamorphosed. Greenstone and amphibolite, metamorphosed from mafic igneous rocks, are dispersed throughout the terrane but make up only a relatively small volume of it. Included within the east half of the terrane is the volcanogenic copper belt, which, in addition to the rocks described above, also contains felsic schist, carbonaceous schist, and marble. The volcanogenic stratabound copper-zinc-lead-silver deposits are generally associated with felsic schist. Metamorphic recrystallization is greatest in the north and central parts of the terrane and becomes progressively less intense at the south edge of the mountains where the rocks are predominantly phyllite. Folding is complex and commonly isoclinal and shows more than one period of deformation. The age of the schist belt rocks may be both Precambrian and Paleozoic. The age of metamorphism of these rocks is controversial; it may have occurred at certain stages in the Precambrian, Paleozoic, and Mesozoic (Gilbert and others, 1977; Turner and

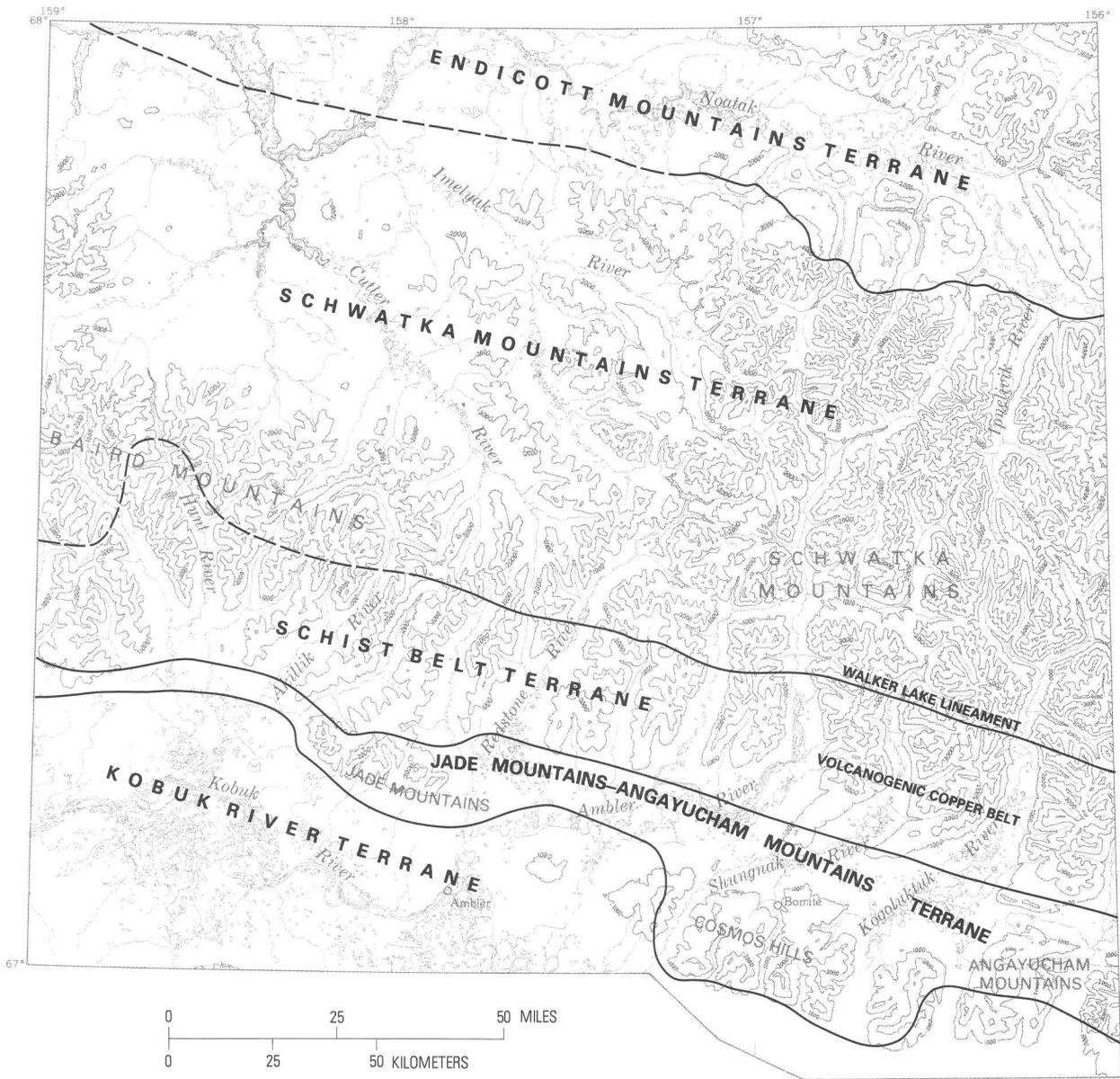


FIGURE 2.—Geologic terranes of the Ambler River quadrangle and the northeastern part of the Shungnak quadrangle.

others, 1978; Smith and others, 1978; Dillon and others, 1980).

The northern contact of the schist belt terrane is a sharp lithologic boundary in the east half of the quadrangle. Fritts (1970) originally called this contact the western extension of the Walker Lake fault that he first mapped in the Survey Pass quadrangle. Later semidetailed maps (Pessel and others, 1973; Pessel and Brosgé, 1977) show that it may instead be a major stratigraphic unconformity. The age of the rocks adjacent to the boundary is not known, and the contact is parallel to the

strike of metasedimentary rocks in most areas. In the west half of the Ambler River quadrangle, the northern boundary of the schist belt is not so sharply defined, possibly because this lithologic break has been folded and faulted along the contact.

The north-central part of the Ambler River quadrangle is herein called the Schwatka Mountains terrane. This terrane consists of a variety of metasedimentary rocks of which the early and middle Paleozoic Skajit Limestone is most widely exposed. Calcareous schist, quartzite, dolomite,

phyllite, and felsic volcanic(?) rocks also make up large parts of this terrane. Metamorphosed granitic plutons of probable middle Paleozoic age have intruded the rocks of the southern part. Recrystallization has obliterated the fossil record in most areas, but it is believed that the rocks are predominantly Paleozoic. The oldest known rocks in this terrane are Ordovician; this age is based on stratigraphic correlation with graptolite-bearing rocks located west of the quadrangle (U.S. Geological Survey, 1975b). The age of the youngest rocks, probably Permian, is based upon stratigraphic correlation with rocks located east of the quadrangle (Mull and TAILLEUR, 1977). The northeast edge of the terrane is overlain by progressively less metamorphosed clastic rocks of Late Devonian age.

The northern part of the Ambler River quadrangle, called the Endicott Mountains terrane (fig. 2), is composed of north-dipping sedimentary rocks that structurally overlie the Schwatka Mountains terrane. It is an allochthonous sequence mostly composed of Late Devonian shale, sandstone, and conglomerate that was deposited as a thick clastic wedge. The rocks were derived from a north-to-east source area (Donovan and TAILLEUR, 1975; Nilsen and others, 1980). These sedimentary rocks and the younger Paleozoic and Mesozoic rocks that stratigraphically overlie them in the Howard Pass quadrangle to the north are distinctly different from the partly coeval sequence of rocks in the Schwatka Mountains terrane. The best explanation for these regional structural and stratigraphic relations is that the Endicott Mountains terrane in the Ambler River quadrangle represents the south edge of the Brooks Range allochthon (Martin, 1970; Mayfield and others, 1978; Ellersieck and others, 1979) and is the lower part of a series of coeval allochthonous sequences that were thrust northward more than 150 km in the Early Cretaceous orogeny to create the bedrock that is exposed in the DeLong and Endicott Mountains of the north half of the Brooks Range (Mull and others, 1976). If this reconstruction is correct, then the Kanayut Conglomerate-Hunt Fork Shale clastic wedge was deposited south of the schist belt terrane and was derived in part from rocks eroded from the Schwatka Mountains terrane, possibly unmetamorphosed parts of the schist belt terrane, and other terranes currently in the subsurface north of the quadrangle.

This hypothesis requires a relatively simple structural history during the Brooks Range

orogeny in which rocks to the south were successively thrust over (or underthrust by) rocks to the north (TAILLEUR and SNELSON, 1969; Mull and others, 1976; Gealey, 1980). Another attraction of this scheme is that it requires the Endicott Mountains terrane and overlying allochthons to be deposited on a continental shelf south of the Schwatka Mountains and schist belt terranes which results in an orderly succession of the major facies patterns from the Devonian to the Jurassic. Some geologists have found this hypothesis unappealing because the Endicott Mountains terrane does not reappear at the south edge of the Brooks Range. For this hypothesis to be correct, it requires that the Endicott Mountains terrane was completely thrust over the Schwatka Mountains and schist belt terranes or that a southward extension of the sequence that contains the Kanayut Conglomerate and Hunt Fork Shale is buried beneath Cretaceous sedimentary rocks south of the Brooks Range.

Dutro and others (1976) favor an alternative explanation for the similar structural position of the Endicott Mountains terrane to the east in the Wiseman quadrangle. They suggest that this terrane was first thrust southward over coeval and older rocks and later was thrust northward to produce the characteristic northward overturned folds and northward directed thrust faults of the Endicott Mountains. This hypothesis requires the source area for the Kanayut-Hunt Fork clastic wedge to be in the subsurface of the North Slope, and it requires a more complex structural evolution for the Brooks Range where southward overthrusting, which is not strongly supported by structural evidence, was followed by northward overthrusting.

Dutro and others' (1976) hypothesis does not take into account the problems that arise in explaining the distinctive allochthons, each composed of Devonian or Mississippian to Cretaceous sedimentary rocks, which structurally overlie and are coeval with the sequence of rocks that contains the Endicott Mountains terrane north and west of the Ambler River quadrangle. If the Endicott Mountains terrane and the structurally higher allochthons were part of the same extensive depositional basin located north of the Schwatka Mountains terrane, as was implied by Dutro and others' (1976) hypothesis, then still left to be explained are (1) how this greater than 250-km-wide Devonian to Jurassic depositional basin became stacked up on itself and (2) how the complex depo-

sitional facies patterns were distributed in northern Alaska prior to the Brooks Range orogeny.

METAMORPHISM

Most rocks in the central part of the Ambler River quadrangle have undergone low-grade regional dynamothermal metamorphism (Winkler, 1979). The structural grain of both the foliation and strike of metasedimentary rocks trends west-northwest following the higher topography of the mountain belt. Metamorphic recrystallization is highest in the central Baird and Schwatka Mountains where fine-grained clastic rocks have been transformed to quartz-mica schist. Flanking the mountains along the Kobuk and Noatak valleys, fine-grained clastic rocks are best described as slate or phyllite. In the southeastern corner of the quadrangle, the Cosmos Hills antiform is ringed by strongly indurated and partially recrystallized metasedimentary rocks, which become progressively more metamorphosed toward the center of the arch to phyllite and quartz-mica schist. Rocks exposed in the axis of the Cosmos Hills antiform resemble rocks in the schist belt both lithologically and in metamorphic grade.

Hundreds of rock samples taken during the course of the current and previous studies in the area have been examined petrographically. A plot of the mineral assemblages was used to construct a map that shows areas of different metamorphic grade (fig. 3). Each grade has common mineral assemblages that reflect differences in temperature and pressure of metamorphism from area to area. Metamorphic grade boundaries are drawn using the classification scheme of Winkler (1979). All boundaries that are shown in the quadrangle are approximate and gradational.

Metamorphic rocks in the quadrangle are broadly grouped into three categories based upon temperatures reached during metamorphism. These categories are very low grade, low grade, and low to medium grade. Very low-grade and low-grade metamorphic rocks constitute the regionally metamorphosed rocks in the quadrangle and are equivalent to the greenschist facies (Turner, 1968). Within areas of low-grade metamorphism, rocks that were metamorphosed under relatively high-pressure conditions are distinguished by the glaucophane zone, and rocks that were metamorphosed under relatively high temperature are

distinguished by the garnet zone. A third category, low- to medium-grade metamorphic rocks, consists of those affected by contact metamorphism near granitic plutons. Rocks shown as contact metamorphic on figure 3 correspond to the albite-epidote-hornfels facies or hornblende-hornfels facies of Turner (1968).

VERY LOW-GRADE METAMORPHIC ROCKS

Metamorphic rocks designated as very low grade occur in the foothills of the Baird and Schwatka Mountains bordering the Kobuk and Noatak River valleys. Most rocks show only partial recrystallization. Fine-grained clastic rocks are slate, and mafic rocks are recognizable in hand specimen as basalt or diabase. Petrographic study of the mafic igneous rocks commonly reveals relict and corroded phenocrysts of augite. Common mineral assemblages include quartz, chlorite, calcite, kaolinite, and pumpellyite. In the Ambler River quadrangle, the mineral most diagnostic of this facies is pumpellyite, which occurs only in mafic igneous rocks or wacke that was, in part, derived from mafic rocks.

LOW-GRADE METAMORPHIC ROCKS

Low-grade metamorphic rocks make up most of the Baird and Schwatka Mountains and also crop out in the core of the Cosmos Hills antiform. Rocks that are believed originally to have been shale show a range of recrystallization from gray phyllite to fine-grained quartz-mica schist. Common mineral assemblages in metasedimentary rocks include quartz, albite, muscovite, chlorite, calcite, tourmaline, and chloritoid. Typical mineral assemblages in metamafic rocks include actinolite, sphene, albite, stilpnomelane, and clinozoisite.

Within the broad area of low-grade metamorphic rocks, the glaucophane zone, indicative of relatively high pressure, and the garnet zone, indicative of relatively high temperature, are also shown on figure 3. They are characterized as follows:

Glaucophane zone.—The glaucophane zone of low-grade metamorphic rocks occurs mainly along a discontinuous linear trend in the central and eastern part of the schist belt. Common minerals are glaucophane or crossite, clinozoisite, stilpnomelane, garnet, paragonite, and rare jadeite

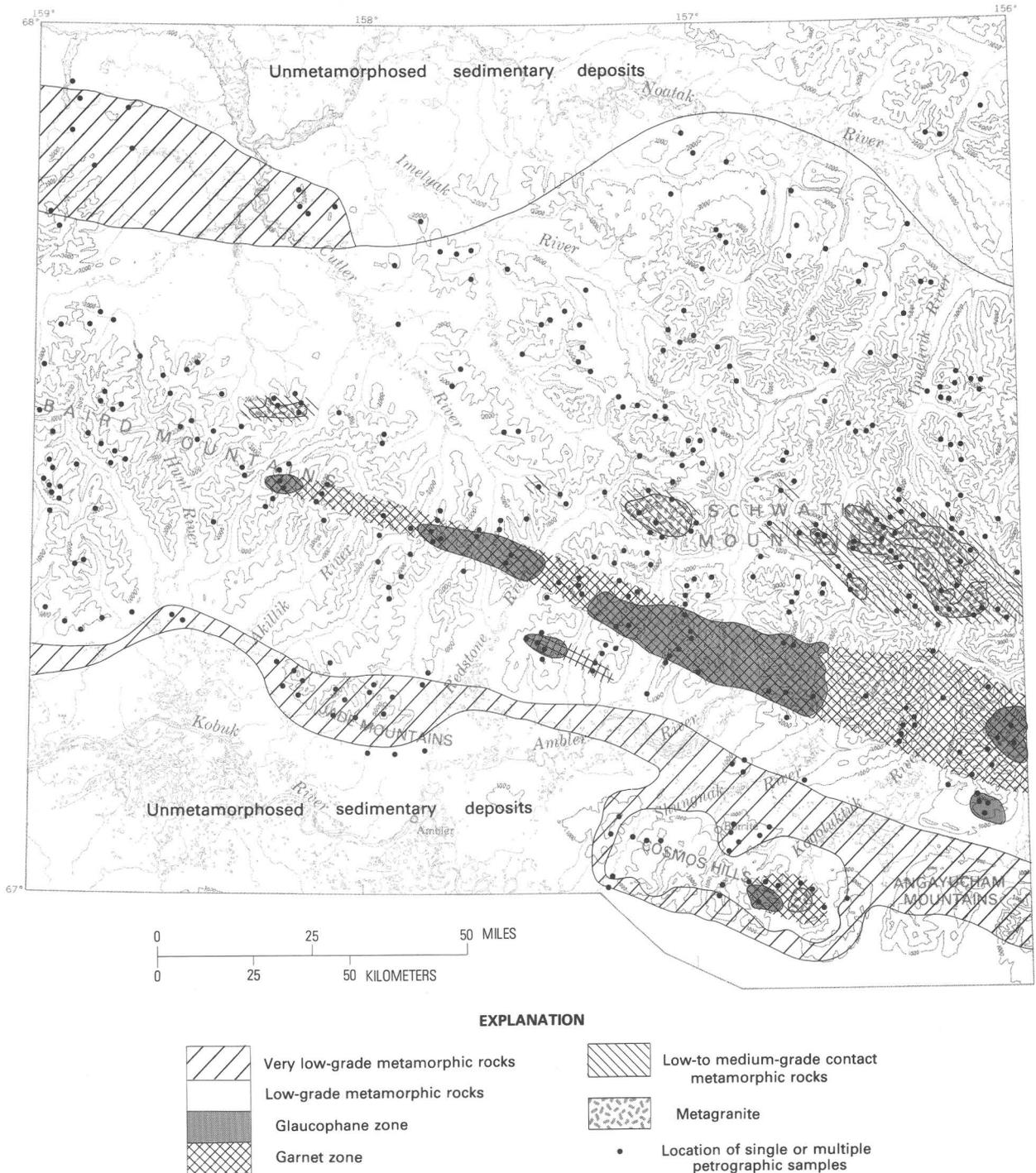


FIGURE 3.—Metamorphic boundaries in the Ambler River quadrangle and the northeastern part of the Shungnak quadrangle.

(Forbes and others, 1974; Gilbert and others, 1977; Carden, 1978). These minerals are found discontinuously in both metasedimentary and metamafic rocks. Glaucophane almost everywhere shows some degree of retrograde alteration to the common minerals of the low-pressure, low-grade meta-

morphic rocks. It is likely that in many areas, glaucophane and jadeite were completely retrograded to lower-pressure mineral assemblages and that the area affected by high-pressure metamorphism was more extensive than is shown on figure 3. The glaucophane zone of metamorphic rocks

(fig. 3) in the Cosmos Hills is in doubt. Tailleux collected glaucophane from a metamorphic float cobble that he believes came from a nearby outcrop, but an attempt by Carden (1978) to recollect glaucophane from outcrops in the vicinity was unsuccessful. It is possible the sample was of glacial origin which, if true, would nullify the evidence for the glaucophane zone in the Cosmos Hills.

Garnet zone.—The garnet zone, especially almandine-rich garnet, is indicative of the higher temperature part of low-grade metamorphism. This mineral occurs in metasedimentary and meta-mafic rocks along a northwest trend in the central part of the schist belt where regional metamorphism was greatest. This zone mostly overlaps the glaucophane zone, but it is more extensive, perhaps because garnet is more stable to retrograde metamorphism at lower pressures than is glaucophane. There is a gradual transition to lower temperature mineral assemblages and smaller mineral grain size of micaceous minerals both to the north and south. Typical mineral assemblages in metasedimentary rocks include quartz, albite, muscovite, chlorite, clinozoisite, garnet, tourmaline, chloritoid, and rare biotite. Metamafic rocks commonly contain green hornblende, garnet, albite, epidote, chlorite, and sphene. In most areas, almandine-spessartine garnet is a common and conspicuous mineral. It occurs as large poikilitic and locally helicitic crystals, many of which are partly or completely altered to chlorite or biotite. In the Cosmos Hills, garnetiferous metasedimentary rocks are dispersed in a wide band around metamorphosed granitic rock cropping out in the Kogoluktuk River valley. This relation suggests that the granitic rock may have produced a thermal halo during metamorphism.

LOW- TO MEDIUM-GRADE CONTACT METAMORPHIC ROCKS

Most contact metamorphic rocks in the quadrangle occur as thin discontinuous hornfels or tactite zones at the borders of a linear trend of granitic plutons north of the most highly recrystallized regionally metamorphosed rocks. Most tactites show some degree of foliation, but in a few localized zones, they appear to be unaffected by dynamothermal metamorphism. In detail, hornfels or tactite zones occur only locally in the areas that are shown as contact metamorphic in figure 3.

Typical mineral assemblages include diopside, wollastonite, garnet, andalusite, tremolite, and biotite. These minerals indicate relatively low pressure conditions and temperatures indicative of both low and medium grades of metamorphism (Winkler, 1979).

HISTORY OF METAMORPHISM

The metamorphic history of the rocks in the Ambler River quadrangle is complex because there is evidence that metamorphism occurred in the middle Paleozoic, Cretaceous, and possibly the late Precambrian. Most geologists who have studied the metamorphic rocks in the Ambler River quadrangle agree that a regional metamorphic event affected the southern Brooks Range in the early and middle Cretaceous, about 130–80 m.y. ago. This concept is strongly supported by the stratigraphic record of regional tectonism at this time and by many potassium-argon dates from metamorphic micaceous minerals in the schists and gneisses (Turner and others, 1979a). Metamorphism probably accompanied downwarping of the south edge of the Alaska Arctic plate as imbricated thrust sheets were stacked above the rocks in the central part of the quadrangle (Gealey, 1980). Later isostatic rebound and erosion of the crustal welt in the southern Brooks Range have exposed these metamorphic rocks throughout the Baird and Schwatka Mountains.

Other radiogenic evidence dates the period of contact metamorphism that coincided with the intrusion of granitic plutons in the central part of the quadrangle during the middle Paleozoic (Dillon and Gilbert, 1978; Nelson and others, 1979). These data are supported by the stratigraphic record of a late Devonian uplift, probably accompanied by block faulting, in the Schwatka Mountains terrane (fig. 2) where the early Mississippian Kekiktuk Conglomerate appears to overlie Devonian and older rocks with an angular unconformity (Mull and Tailleux, 1977; Mayfield and Tailleux, 1978). Although the details of the late Devonian uplift are sketchy, there appears to be little evidence that the period of contact metamorphism coincided with a regional dynamothermal metamorphic event.

Scattered potassium-argon metamorphic mineral ages in the Precambrian and Paleozoic suggest to Turner and others (1979a, b) that the

southern Brooks Range was affected by an earlier period of regional high-pressure metamorphism that produced the glaucophane mineral assemblages in the late Precambrian. These data are supported by textural evidence from the metamorphic minerals which indicates that glaucophane and jadeite crystallized at an early stage in the metamorphic process and were later retrograded to lower pressure mineral assemblages (Forbes and others, 1974; Mayfield, 1976; Gilbert and others, 1977; Carden, 1978). The interpretation of a late Precambrian metamorphic event in some rocks of the schist belt terrane (fig. 2) is complicated by the fact that all the rocks of this area were metamorphosed in the Cretaceous age. Some of the alleged Precambrian glaucophane-bearing rocks occur in the volcanogenic copper belt (fig. 2) closely associated with middle Paleozoic igneous and sedimentary rocks. Wiltse and Gilbert (1977) believe that the middle Paleozoic rocks were deposited unconformably upon a Precambrian basement, and during the Cretaceous regional metamorphism, the Precambrian and Paleozoic rocks became tectonically intercalated (Gilbert and others, 1977). Other geologists remain skeptical of these interpretations, which are based on mapping and sampling in an area of rocks that is recrystallized and isoclinally folded. To the west in the Baird Mountains quadrangle where the rocks are not so strongly recrystallized, glaucophane has been found in mafic igneous rocks lying between homoclinally dipping fossiliferous middle Paleozoic limestones ($67^{\circ}25'$ latitude, $162^{\circ}35.5'$ longitude). Nearby mafic igneous rocks, which appear similar to those with glaucophane, have intruded the limestones. If these relations are interpreted correctly, field observations require the unlikely geographic coextension of two separate glaucophane events, one that occurred in the late Precambrian and one that occurred after the middle Paleozoic. Reconciling the field observations with the Precambrian radiogenic age dates remains an important unresolved problem concerning the metamorphic rocks in the south-central and southwestern Brooks Range.

POTASSIUM-ARGON AGES

All potassium-argon ages in the quadrangle are located on figure 4 and listed in table 2. Most dates previously reported in various other publications

are summarized by Turner and others (1978; 1979a). Ages from localities 26 and 27 are published here for the first time. The potassium-argon date from locality 27 may represent a minimum age for detrital muscovite in a feldspathic wacke rock unit. Since all the other ages are from rocks partly or completely recrystallized by metamorphism, the minerals that were dated either formed under metamorphic conditions or had their radiogenic constituents affected by a later metamorphism.

Study of table 2 reveals a wide spread of potassium-argon ages ranging from Precambrian to Cretaceous. Almost all ages obtained from muscovite and biotite fall in the Cretaceous between 130 and 88 m.y. These dates are believed to reflect the last stage of regional metamorphism in the area which coincides with the period of most intense tectonic activity associated with the Brooks Range orogeny (Tailleur and Brosgé, 1970). Ages obtained from glaucophane and actinolitic hornblende present a much more complex and controversial picture. These amphibole ages range from 2,255 to 163 m.y. ago. Most pre-Cretaceous ages cannot be taken at face value because there are too many instances where similar rocks located in a similar stratigraphic setting give widely divergent ages. Glaucophane samples yielding ages greater than 1 b.y. are believed to have been affected by excess argon so that they represent values that are too old by an undetermined amount (Turner and others, 1979a). A group of potassium-argon ages in the 760 to 570 m.y. range suggests that many of the rocks may have been subjected to a late Precambrian period of regional metamorphism. Under this hypothesis, the various Paleozoic and Mesozoic ages between 560 and 150 m.y. may represent partial argon loss due to the later Cretaceous metamorphic event. A more complete discussion of this idea is presented by Turner, Forbes, and Mayfield (1978) and Turner, Forbes, and Dillon, (1979a, b).

URANIUM-LEAD AGES

U-Pb ages from two duplicate samples are reported by Dillon and others (1979); Dillon and others (1980) using the mineral zircon separated from blastoporphyratic schist (informally called the "button schist" by some geologists) and collected at the Arctic deposit in the volcanogenic

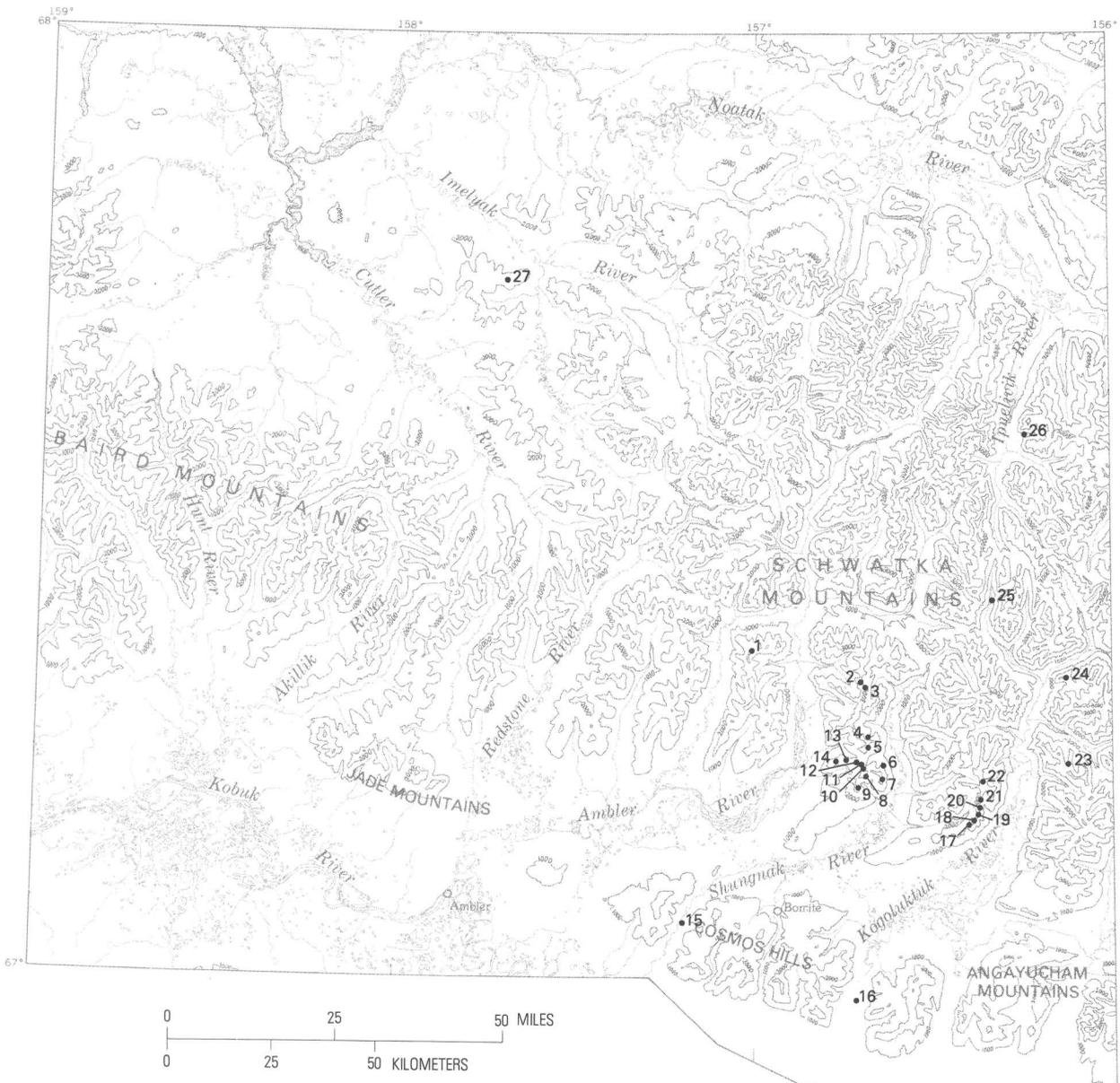


FIGURE 4.—Location of rocks that have been dated by radiogenic methods in the Ambler River quadrangle and the northeastern part of the Shungnak quadrangle. Numbers refer to listings in tables 2, 3, and 4.

copper belt (table 3 and fig. 4). The ages from these samples, when combined with U-Pb ages from other similar granitic and rhyolitic rocks east of the Ambler River quadrangle, form a chord on a $^{206}\text{Pb}/^{238}\text{U}$ diagram that intersects concordia at about 360 m.y. and 80 m.y. The intersections of the chord of the U-Pb dates and the concordia curve are interpreted by Dillon to indicate an approximate late Devonian crystallization age for the zircons in the copper belt volcanic rocks and an episodic lead loss from zircon sometime between

the Devonian and the end of Cretaceous regional metamorphism. Smith and others (1978) also report Paleozoic model lead ages, ranging from 350 to 250 m.y., from the sulfide samples in metavolcanic rocks in the volcanogenic copper belt (fig. 2).

LEAD-ALPHA AGES

Two lead-alpha dates have been determined using zircon separated from metagranites, one from

TABLE 2.—Potassium-argon ages from the Ambler River quadrangle¹

Location No. on figure 4	Sample no.	Source	Rock type	Mineral dated	Average K ₂ O (weight percent)	⁴⁰ Ar _{rad} (mol/g) × 10 ⁻¹¹	⁴⁰ Ar _{rad} (percent)	Age in million years plus or minus analytical uncertainty
1	-----72E100R	Turner and others (1978; 1979a)	Quartz muscovite schist	Muscovite	10.245	197.4	93.1	129 ± 3.9
2	-----73RR75-3	do	Actinolite schist	Impure actinolite	.071	3.973	64.1	352 ± 17.7
3	-----74AWM309	do	Actinolite quartz chlorite schist	Actinolite	.075	5.335	49.9	435 ± 30.5
4	-----73RR52	do	Garnet glaucophane schist	Glaucophane (I) Glaucophane (II)	.035 .035	3.705 3.979	66.9 68.7	621 ± 31 659 ± 33
5	-----73RR54	do	Garnet glaucophane schist	Glaucophane	.037	15.08	81.7	1,694 ± 85
6	-----72E56B	do	Biotite muscovite schist	Muscovite	11.000	307.2	88.1	184 ± 5.5
7	-----C-2	do	Garnet glaucophane schist	Glaucophane	.044	12.60	86.9	1,338 ± 134
8	-----73RR10-1C	do	Quartz muscovite schist	Muscovite	9.695	190.2	87.5	131 ± 3.9
9	-----73RR45C	do	Actinolite schist	Actinolite	.111	2.722	41.8	163 ± 6.6
10	-----73RR7G	do	Glaucophane quartz muscovite schist	Glaucophane Muscovite	.038 5.061	3.867 96.31	52.5 65.1	597 ± 59 128 ± 4
11	-----73RR6EF	do	Biotite feldspar quartz muscovite schist	Biotite (I) Biotite (II) Muscovite	9.530 9.530 11.197	147.2 149.2 190.2	88.8 93.4 92.8	105 ± 3 106 ± 3 115 ± 3
12	-----73RR18F	do	Biotite quartz muscovite schist	Biotite Muscovite	9.118 10.837	180.0 210.3	91.0 84.9	132 ± 4 130 ± 4
13	-----A-1	do	Garnet glaucophane schist	Glaucophane (I) Glaucophane (II) Glaucophane (III)	.012 .012 .012	9.581 9.530 9.570	45.4 67.2 63.2	2,535 ± 507 2,555 ± 511 2,535 ± 507
	A-1CNM	do	Garnet glaucophane schist	Paragonite	.430	15.86	32.2	239 ± 7

TABLE 2.—Potassium-argon ages from the Ambler River quadrangle¹—Continued

Location No. on figure 4	Sample no.	Source	Rock type	Mineral dated	Average K ₂ O (weight percent)	⁴⁰ Ar _{rad} (mol/g) × 10 ⁻¹¹	⁴⁰ Ar _{rad} (percent)	Age in million years plus or minus analytical uncertainty
A-2		do	Garnet glaucophane schist	Glaucophane Paragonite	.028 5.550	7.501 18.37	83.9 48.1	1,279 ± 256 218 ± 6
A-3		do	Garnet glaucophane schist	Glaucophane Paragonite	.015 .640	4.741 21.75	76.7 78.2	1,437 ± 359 222 ± 7
14 -----	73RR31C	do	Glaucophane schist	Impure glaucophane	.028	2.681	56.8	2569 ± 68
15 -----	55ATr109	do	Tremolite schist	Tremolite	.030	1.456	30.3	314 ± 31
16 -----	65APa44	Patton and others (1968)	Meta-granite	Hornblende	.751	13.90	93.0	124 ± 4
17 -----	75AWM1503.1	Turner and others (1978, 1979a)	Quartz muscovite schist	Muscovite	9.946	160.4	88.9	109 ± 3
18 -----	75AWM1502	do	Actinolite schist	Actinolite	.077	4.932	38.0	396 ± 16
19 -----	74AWM1535.3	do	Feldspathic schist	Biotite Muscovite	8.650 10.539	149.4 188.3	91.5 94.3	116 ± 4 120 ± 4
20 -----	73ATr105.4	do	Biotite muscovite feldspar schist	Biotite Muscovite	8.228 11.135	127.8 190.3	74.9 84.9	105 ± 3 115 ± 3
21 -----	75AWM1500	do	Feldspathic schist	Muscovite	10.805	266.0	89.2	163 ± 5
	75AWM1501.1	do	Feldspathic schist	Muscovite	10.758	191.7	87.5	120 ± 4
22 -----	74AWM1745.5	do	Skarn	Actinolite	.262	9.954	81.2	246 ± 15
23 -----	72Pe92	do	Meta-granite	Biotite (I) Biotite (II) Muscovite	8.435 8.435 10.983	111.4 109.5 189.1	85.2 80.7 95.8	89.5 ± 3 88 ± 3 116 ± 3
24 -----	72E222	do	Meta-granite	Biotite Muscovite	8.605 10.955	122.1 162.6	92.7 95.0	96 ± 3 100 ± 3
25 -----	60ATr134	Pessel and others (1973)	Meta-granite	Muscovite	10.520	157.6	91.0	101 ± 2
26 -----	75Tr142.2E ³	This report	Amphibolite	Hornblende	.773	485.6	91.0	391 ± 20
27 -----	76Tr75B ³	This report	Wacke	Detrital muscovite	8.530	602.7	91.0	434 ± 22

¹[Previously published dates have been recalculated using new decay constants.] Constants used in calculation of ages: $\lambda_e + \lambda_{e'}$ = 0.581×10^{-10} yr⁻¹
 λ_B = 4.963×10^{-10} yr⁻¹
 $^{40}\text{K}/\text{K}_{\text{total}}$ = 1.167×10^{-4} Atom/Atom

²Minimum age.

³Analyses by M. S. Robison, Teledyne Isotopes (argon), and Paul Klock, U.S. Geological Survey (potassium).

TABLE 3.—Uranium-lead ages from the Ambler River quadrangle

Location No. on figure 4	Sample no.	First publication	Rock type	Mineral dated	Ages (m.y.)		
					$^{206}\text{Pb}^*/^{238}\text{U}$	$^{207}\text{Pb}^*/^{235}\text{U}$	$^{207}\text{Pb}^*/^{206}\text{Pb}$
20 -----	77DN76	Dillon and Pessel, 1979	Blastoporphyritic schist	Zircon	329	334	373
20 -----	77Mw76	do	do	do	327	332	364

the Cosmos Hills and the other from the upper Kogoluktuk River near Schishakshinovik Pass (table 4 and fig. 4). These ages were determined in 1960 and 1961 during the early years of lead isotope dating techniques and therefore should not be used as specific dates, because it is probable that lead and uranium gain or loss has affected the ages by an indeterminable amount. However, these dates suggest that the metagranites are pre-Cretaceous in age, especially in light of more recent U-Pb dates (Dillon and others, 1979) and Rb-Sr dates (Nelson and others, 1979) from similar granitic rocks in the Survey Pass quadrangle.

FOSSIL LOCALITIES

Outcrops where fossils have been collected are shown on figure 5, and a list of the type of fossil(s), age, and geologic rock unit in which they were found is given in table 5. Fossil ages range from Ordovician to Mississippian. Most fossils come from partially recrystallized carbonate rocks mapped as the Baird Group, Skajit Limestone, Lisburne Group, and various small unnamed limestone beds within clastic rock units. A detailed discussion of Paleozoic corals from collections in carbonate rocks in the southern part of the quadrangle is reported in Oliver and others (1975). Conodonts identified from the northern part of the quadrangle have color alteration indexes of 5-5 1/2, indicating postdepositional temperatures of

300°-400°C. The only fossils which have been found in non-carbonate rocks are Silurian graptolites from dark-gray slates in the northwestern part of the quadrangle.

COMPONENT MAPS OF THE AMBLER RIVER QUADRANGLE FOLIO

GEOLOGY REPORT OF 78-120-A

The first component of the Ambler River folio is the geologic map published at 1:250,000 scale, and a generalized version appears on the base maps for many of the other folio components. Most rocks in the quadrangle have been tectonically disturbed and metamorphosed to such an extent that fossil evidence has been obliterated from many of the rock units, thus making it difficult to construct a complete stratigraphic column. Without a coherent stratigraphic column, many of the major folds and faults in the quadrangle are unrecognized. To enable the reader of the map to understand the degree of uncertainty attached to the age of various map units, sedimentary and metasedimentary rocks are divided into categories of certain and uncertain age. Among the rocks of uncertain age, some are given queried systemic age assignments usually based on tenuous correlations with other rocks located some distance away, commonly outside the quadrangle.

TABLE 4.—Lead-alpha ages from the Ambler River quadrangle
[Lead-alpha determinations by T. W. Stern 1960-61]

Location No. on figure 4	Sample no.	First publication	Rock type	Mineral dated	$\alpha/\text{mg-hr}$	Pb (ppm)	Age (m.y.)
25 -----	60ATr134	This report	Metagranite	Zircon	1,236	105	210 ± 25
16 -----	55ATr149	do	do	do	2,125	420	490 ± 60

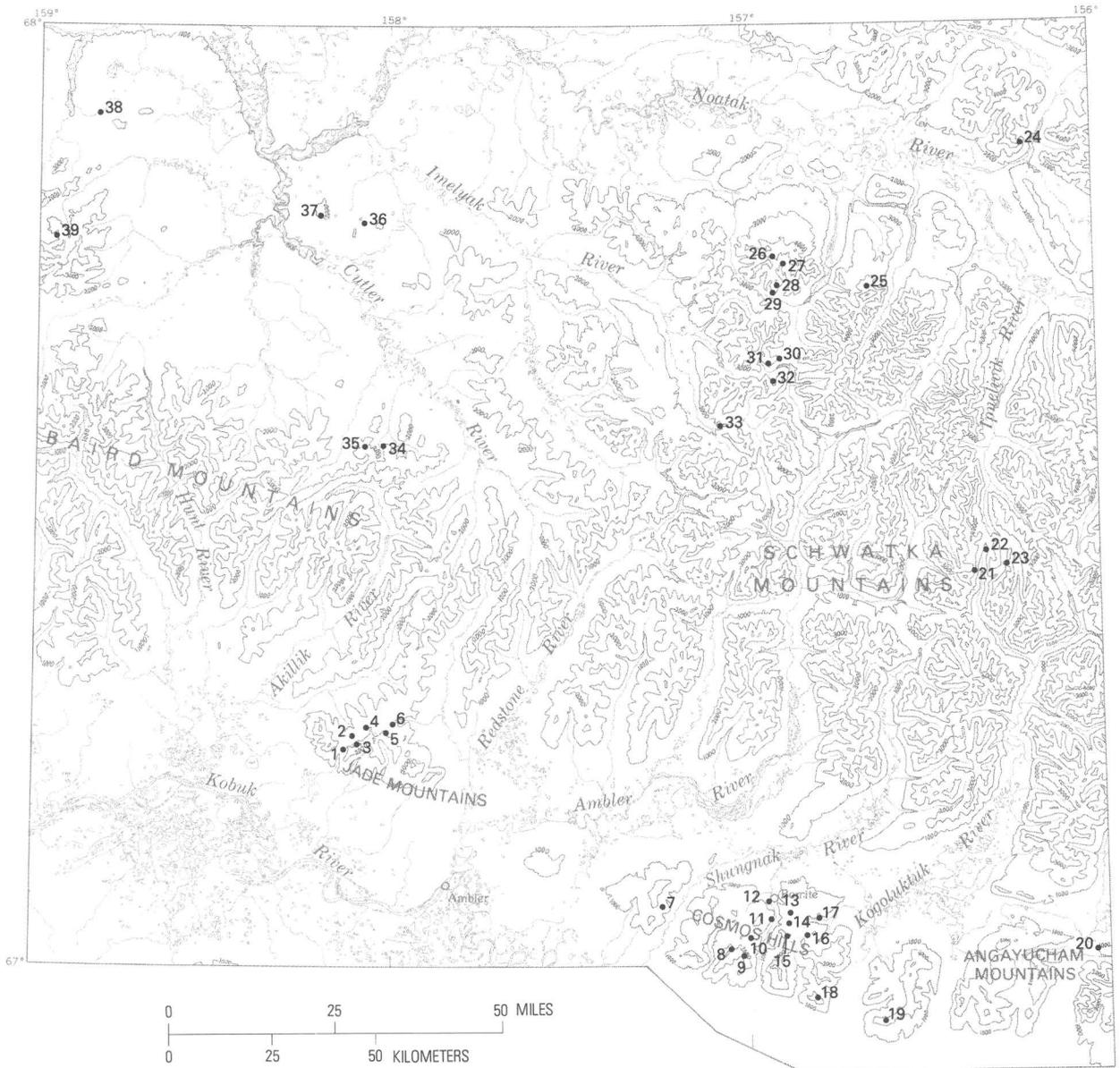


FIGURE 5.—Fossil localities in the Ambler River quadrangle and the northeastern part of the Shungnak quadrangle. Numbers refer to listing in table 5.

Since the publication of the geologic map, radiogenic age dating work on some granitic rocks in the Ambler River and adjacent Survey Pass quadrangles shows strong evidence that the time of igneous cooling of both rhyolitic metavolcanic rocks in the southeastern part of the quadrangle and the granitic metaplutonic rocks stretching across the central part of the quadrangle is middle Paleozoic. Dillon and Gilbert (1978) have determined that the megacrystic felsic schist in the Ambler River quadrangle is approximately 360 m.y. old by U-Pb

dating methods on zircon. Recent dates from granitic plutonic rocks in the central part of the Survey Pass quadrangle by Nelson and others (1979) using Rb-Sr methods and by Dillon and Gilbert (1978) using U-Pb methods also support a middle Paleozoic age for these rocks. Because the granitic plutonic rocks stretching across the central part of the Ambler River quadrangle are mineralogically similar and crop out on the same linear belt, they are also probably middle Paleozoic. These rocks are shown on the map as Cretaceous,

TABLE 5.—Fossils collected in the Ambler River quadrangle

[Field samples listed as Lehner, Babcock, Read, and Bornite are from collections of Bear Creek Mining Co.; sample numbers beginning with 69A and 685 are from collections of Alaskan Division of Mines and Geology (Fritts, 1969a; 1970); and remaining samples are from the collections of the U.S. Geological Survey. The geologic units are on the geologic map of Mayfield and Tailleux (1978)]

Location No. on figure 5	Field sample	USGS collection No.	Fossils	Age	Geologic map unit	Determined by
1 -----	66APa99	7983-SD	Corals, stromatoporoids	Silurian or Devonian	Limestone of Baird Group	W. A. Oliver
2 -----	66APa97, 66APa98, 73ATr85	7981-SD, 7982-SD, 9278-SD	Corals, fish bones	Devonian	do	W. A. Oliver D. H. Dunkle
3 -----	73ATr82.2, 73ATr82.3	9276-SD, 9277-SD	Corals	Middle Devonian	do	W. A. Oliver
4 -----	Babcock 119 66ARr26	6668-SD 7984-SD	Corals, gastropods, stromatoporoids	Early(?) and Middle Devonian	do	do
5 -----	Babcock 117	6669-SD	Corals, stromatoporoids	Probably Middle or early Late Devonian	do	do
6 -----	66ATr18	7985-SD	Corals	Middle or early Late Devonian	do	do
7 -----	69A34B	8742-SD	do	Late Silurian to Middle Devonian	do	do
8 -----	Lehner	6462-SD	do	Probably Devonian	do	do
9 -----	69A12b, c, f	8740-SD	Corals, crinoids	do	do	do
10 -----	69A15		Corals	Paleozoic	Undifferentiated limestone and marble unit	C. E. Fritts ¹
11 -----	69A13g	8741-SD	do	Silurian or Devonian	Limestone of Baird Group	W. A. Oliver
12 -----	Bornite cores	8741-SD	do	Early(?) and Middle Devonian	do	do
13 -----	65ABe74A	7471-SD	do	do	do	do
14 -----	55ATr107, 65ABe66, 66ABe104, 69A6 Read A	6460-SD, 7659-SD 7980-SD, 8738-SD 6460-SD	Corals, brachiopods	do	do	W. A. Oliver C. W. Merriam
15 -----	Read B 65B73	6461-SD	do	do	do	W. A. Oliver; J. T. Dutro, Jr.
16 -----	69A10B	8739-SD	Corals, stromatoporoids	Probably Middle or early Late Devonian	do	W. A. Oliver
17 -----	69A21d, e, g, h, i		Brachiopods, corals gastropods	Middle Devonian(?)	do	W. A. Oliver E. L. Yochelson
18 -----	68S18		Crinoids	Paleozoic	Limestone in mafic volcanic rocks unit	C. E. Fritts ¹
19 -----	68S51p-k		Crinoids, conodonts	do	Limestone in mafic volcanic rocks unit	J. W. Huddle
20 -----	65AMm34	7996-SD	Corals, stromatoporoids	Probably Middle or early Late Devonian	Undifferentiated limestone and marble unit	W. A. Oliver C. W. Merriam
21 -----	55ATr129G	M1048	Crinoids, ostracods, and bryozoan?	Paleozoic	Kayak Shale	A. K. Armstrong

TABLE 5.—Fossils collected in the Ambler River quadrangle—Continued

Location No. on figure 5	Field sample	USGS collection No.	Fossils	Age	Geologic map unit	Determined by
22 -----	66ABe75 55ATr132	M1004 18631-PC	Corals, sharks teeth, and brachiopods	Late Mississippian	Lisburne Group	A. K. Armstrong Helen Duncan D. H. Dunkle
23 -----	72ATr28 76ATr96 76ATr96B	M1052 25057-PC (M1300) 27437-PC	Corals, molluscs, brachiopods, gastropods conodonts, and crinoids	Late and Early Mississippian	Lisburne Group and Kayak Shale	A. K. Armstrong J. W. Huddle J. E. Repetski
24 -----	76AMd241		Crinoids	Probably Late Devonian	Sandstone, siltstone, and slate unit	J. T. Dutro, Jr.
25 -----	76ATr190E	8669-CO	Conodonts	Middle Ordovician to Early Silurian	Siltstone and slate unit	J. E. Repetski A. G. Harris
26 -----	76ATr147C	9692-SD	Corals, gastropods, bryozoan, and brachiopods	Silurian or Devonian	do	do
27 -----	76Md274		Cephalopods, conularids and stromatoporoids	Probably Silurian or Devonian	do	J. T. Dutro, Jr. W. A. Oliver
28 -----	76ATr148A		Corals	do	Skajit Limestone	do
29 -----	76ATr149C	9693-SD	do	Late Silurian to Middle Devonian	do	do
30 -----	76Hn29 66ARr24A	M1302 M1048	Crinoids, corals	Ordovician to Silurian	Limestone with black chert of Lisburne(?) Group	A. K. Armstrong
31 -----	76ATr85B	M1301	Corals	Paleozoic	Limestone with black chert of Lisburne(?) Group	do
32 -----	76ATr86B	9803-SD	Conodonts, corals	Middle Ordovician to Middle Devonian	Skajit Limestone	J. E. Repetski A. G. Harris A. K. Armstrong
33 -----	55ATr121		Ostracodes	Paleozoic	Stream float	J. M. Berdan
34 -----	76Md235C		Gastropods, brachiopods	Paleozoic	Skajit Limestone	J. T. Dutro, Jr.
35 -----	76ATr118A, C, D,	9691-SD	Stromatoporoids	Probably Silurian or Devonian	do	W. A. Oliver
36 -----	76ATr3E	9802-SD	Conodonts	Middle Ordovician to Middle Devonian	Limestone clasts in feldspathic wacke unit	J. E. Repetski A. G. Harris
37 -----	76ATr5	9598-SD	Corals	Probably Silurian or Devonian	Skajit Limestone	W. A. Oliver
38 -----	76AMd32		Graptolites	Middle Silurian	Black phyllite and siliceous phyllite unit	Claire Carter
39 -----	76ATr50E	8668-CO	Conodonts	Ordovician, probably Early or Middle	Undifferentiated Limestone and marble unit	J. E. Repetski A. G. Harris

¹Field identification by C. E. Fritts of Alaskan Division of Mines and Geology.

but for the above-stated reasons are now regarded as probably being middle Paleozoic.

The geologic map of the Ambler River quadrangle shows only bedrock units. Those interested in geology of surficial deposits should consult the maps of Pessel and Brosgé (1977) and Fernald (1964).

RECONNAISSANCE GEOCHEMISTRY REPORTS OF 78-120-B THROUGH H

Geochemical studies in the Ambler River quadrangle were made to define areas of anomalous concentrations of selected metallic and non-metallic elements. A sampling program was undertaken during the summer months of the years 1972, 1973, 1974, and 1976, in which 1,281 stream-sediment samples were collected, averaging about one sample per 9 km² in areas where outcrops are exposed. This sampling density completes coverage of the quadrangle on a reconnaissance basis. Extensive Quaternary deposits which cover most of the Noatak and Kobuk valleys (about 25 percent of the quadrangle) were not sampled.

There are several previously published geochemical studies in the Ambler River quadrangle; most are incorporated into this folio. Three reports by the Alaska Division of Geological and Geophysical Surveys (Garland and Pessel, 1975; Garland and others, 1975; Pessel, 1976) present analyses of 657 stream-sediment samples from the Ambler River quadrangle. These samples have been included in the present compilation, along with 561 samples collected by the U.S. Geological Survey which are reported for the first time (OF 78-120-B, C). Two reports by Fritts (1969a; 1970) are not included in this compilation. They present the analyses of 236 stream-sediment samples in the Cosmos Hills, including part of the Shungnak quadrangle adjacent to the Ambler River quadrangle. The samples were collected at 200- to 500-m intervals along a few creeks, a more concentrated and less uniform distribution than in the rest of the quadrangle. Some elements reported by Fritts have significantly higher median values than the values given in other reports on geochemistry of the Ambler River quadrangle, so these values are excluded from this compilation.

Samples were collected if possible from fine sediment in streams which drain bedrock. If no silt was present in the stream bed, samples were taken

from alluvium on the bank or from around the roots of plants near the water's edge. The samples were sieved to retain the -80 mesh fraction, which was composed of clay and very fine silt. One split of each sample was analyzed by the atomic absorption method for copper, lead, and zinc. Samples collected in 1974 and 1976 were also analyzed for gold by the atomic absorption method. Another split of each sample was analyzed by the semi-quantitative emission spectrographic method for 30 elements.

The analyses for the stream-sediment survey are listed by Ellersieck (1978a), and the sample locations are plotted on a generalized geologic map by Ellersieck (1978f). A threshold limit above which a sample is considered to be anomalous has been chosen for each element. These levels are determined entirely from data within the Ambler River quadrangle; therefore, they may be higher or lower than thresholds in other regions of different geology or stream chemistry. Because the data are reported in discrete analytical intervals, the distribution curve of elemental concentrations is not smooth, and the number of anomalous samples is different for each element. The proportion of anomalous samples may be as high as 9.8 percent (strontium) or as low as 0.7 percent (chromium); the average is 3.5 percent of the total number of samples.

There are five geochemical anomaly maps in the folio (Ellersieck, 1978b, c, d, e, g) which show the location of anomalies for the following 12 elements: copper, molybdenum, lead, zinc, barium, silver, arsenic, tin, beryllium, chrome, nickel, and cobalt. These elements were chosen either because they are of possible economic significance or because they appear to be related to the types of mineral deposits that could be found in the quadrangle.

An estimate of the effectiveness of the sample density of this survey can be made by calculating the percentage of known mineral occurrences that have a geochemical sample site within 5 km downstream and are reflected by anomalously high geochemical sample values for any of the commodities reported in the occurrence. Occurrences in the Cosmos Hills, nonmetallic mineral occurrences, claims, and occurrences that were determined to exist on the basis of the stream-sediment survey are excluded from consideration. Of the 53 mineral occurrences in the area of the geochemical survey, 39 (74 percent) had at least one stream-sediment sample within 5 km downstream. Of these 39 oc-

currences, 25 (64 percent or 47 percent of the 53 total occurrences) showed anomalous concentrations of silver, copper, lead, zinc, or an element reported to be in the occurrence by Mayfield and Grybeck (1978). On the basis of these crude assumptions, less than half of the known mineral occurrences are reflected in stream-sediment samples with anomalously high values.

There are many reasons why sample density and sample techniques such as those used are not more effective in finding mineral occurrences. The "halo" of geochemically enriched stream sediments near a mineral deposit is dependent upon a number of complex factors. For example, some deposits may spread their geochemical signatures farther than others, or the principal commodities may be effectively sampled only by a panning technique (not used in this survey). Therefore, a survey of this type cannot be expected to locate significant numbers of specific undiscovered mineral occurrences; instead it is most valuable for delineating broad areas with favorable resource potential and a few specific stream drainages that deserve more detailed exploration.

MINERAL OCCURRENCES AND RESOURCES
REPORT OF 78-120-1

The mineral occurrences and resources map of the Ambler River quadrangle is intended to show three important kinds of mineral information. First, it shows the known mineral occurrences in the quadrangle. Second, it provides a discussion of the important mineral resources. Third, it delineates areas within the quadrangle that have a high potential for discovery of certain types of deposits which could yield significant mineral resources.

There are 80 mineral occurrences in the quadrangle that were known to us at the time of publication of this map. The mineral occurrences are listed numerically in a table accompanying the map. Each numbered occurrence is located on the 1:250,000-scale map of the Ambler River quadrangle, and the principal mineral commodities of interest are shown at each location. In addition, the table provides information on the form and description of the occurrence, the status of development, and the source from which information was obtained.

The map includes a discussion of the known and potential mineral resources of the Ambler River

quadrangle. The most important resources include copper, zinc, lead, and silver; these occur in volcanogenic and carbonate breccia-type deposits. Of the nine known volcanogenic deposits in the quadrangle, one has reserves of 30 million tons of 4 percent Cu, 5.5 percent Zn, 1 percent Pb, and 54.1 g/ton (15 oz/ton Ag), and the other eight are of unknown size and grade. The number of undiscovered deposits at or near the surface is estimated by using areas of favorable geology and geochemical anomalies. Grade and tonnage of possible undiscovered deposits are estimated using data compiled on Canadian volcanogenic deposits of Phanerozoic age. Table 6 shows a crude assessment of the number, grade, and tonnage of undeveloped and undiscovered volcanogenic deposits in the quadrangle. The volcanogenic deposits of this district are at an early stage of development by mining companies, and until more public information is available about the known deposits, the assessment given above should be regarded only as an initial estimate. No attempt is made numerically to assess the base metal resource in carbonate breccia deposits because reserves at the few known deposits are not publically available and the origin of these deposits is speculative. At the largest deposit of this type, Ruby Creek, the reserves are significant. The largest known deposits of jade in Alaska occur in the quadrangle. Though these deposits have a subordinate resource potential, they are expected to provide a steady supply of jade for many years.

The third aim of the mineral occurrences and resources map is to show areas which have high potential for future discoveries of deposits that could provide significant amounts of mineral resources. Four categories of these deposits are

TABLE 6.—*Estimate of number, grade, and tonnage of volcanogenic deposits*

Chance ¹ (percent)	metric tonnage	Grade ²
95	200,000	6-10 percent combined Cu, Pb, Zn, and Ag
55	1,000,000	do
12	10,000,000	do
2	100,000,000	do

¹Crude estimate of number of undiscovered deposits
90 percent chance that there are 7 or more undiscovered deposits
50 percent chance that there are 10 or more undiscovered deposits
10 percent chance that there are 12 or more undiscovered deposits

²Estimate of probable grades of volcanogenic deposits

delineated on the same map as the known mineral occurrences. These categories are (1) volcanogenic deposits, (2) carbonate breccia deposits, (3) black pyritic phyllite deposits, and (4) jade, podiform chromite, and asbestos deposits. An accompanying explanation for favorable mineral resource areas provides a list of the reasons for selection of the specific areas based on geologic, geochemical, geophysical, and telegeologic information available in other segments of the Ambler River folio. Without detailed exploration and drilling, it is impossible to ensure that all favorable areas shown will actually contain deposits.

INTERPRETATION OF LANDSAT IMAGERY REPORT OF 78-120-J

The interpretation of Landsat imagery of the Ambler River quadrangle was made by using a black-and-white Landsat mosaic (band 7) of the State of Alaska assembled by the U.S. Department of Agriculture and by using computer-enhanced black-and-white and color Landsat imagery processed by the U.S. Geological Survey in Flagstaff, Ariz. The mosaic of the Ambler River quadrangle is made from parts of three scenes, 1707-21385 and 1707-21391, taken June 30, 1974, and 1758-21201, taken August 20, 1974. Color computer-enhanced maps include linearly stretched standard false-color, sinusoidally stretched false-color, and simulated natural color images. A black-and-white vertical first-derivative image was also used. Copies of these products are available at nominal cost from the EROS Data Center, Sioux Falls, S. Dak. (Albert, 1978). Detailed descriptions of the various computer enhancement techniques used in these images are given by Albert and Steele (1976a, b) and Condit and Chavez (1978).

Interpretation of Landsat imagery for this folio consists of the identification of straight, circular, and arcuate lineaments and iron-oxide colored areas plotted on 1:250,000-scale maps of the Ambler River quadrangle. It is hoped that some of these features may prove to be directly or indirectly related to important mineral deposits even though a consistent correlation between known deposits and sets of lineaments has not yet been found in this study.

A number of straight lineaments correspond to mapped faults, and some of these indicate that the faults may extend beyond their mapped limits. A

major east-trending broad lineament zone was identified closely corresponding to the Kobuk Trench (Grantz, 1966) and partially corresponding to a regional magnetic discontinuity (Gilbert and others, 1977; Hackett, 1980).

In previous studies, most circular features have been spatially associated with igneous activity, whereas arcuate features have been spatially associated with either igneous activity or metamorphism (Albert and Steele, 1976b). A circular feature centered on metagranitic plutonic rocks, west of the Ambler River in the central part of the quadrangle, is the only obvious spatial correspondence between circular features and igneous phenomena observed in the Ambler River quadrangle. It is possible that Cretaceous regional metamorphism has overprinted and obscured arcuate lineaments related to granitic plutonism.

Many of the iron-oxide colored areas identified on Landsat imagery were observed in the field from aircraft. A substantial number of these occur within carbonate rock units, many of which have not received adequate follow-up exploration. Many of the carbonate rocks observed in the field showed some degree of iron-oxide staining, and most of these could not be identified on Landsat imagery. Several of the iron-oxide areas identified on Landsat imagery, however, correspond to known mineral occurrences and (or) to geochemical anomalies.

AEROMAGNETIC MAP AND INTERPRETATION REPORT OF 78-120-K

The aeromagnetic interpretation of the Ambler River quadrangle is compiled on three sheets: the aeromagnetic-contour map, the magnetic-lineament and anomaly-trend map, and the geologic-interpretation map. The contoured aeromagnetic map appears at 1:250,000 scale on sheet 1. An aeromagnetic survey of the quadrangle and adjacent areas was flown by Geometrics of Sunnyvale, Calif., in 1974 and 1975 for the Alaska Department of Natural Resources. The magnetic data were collected along north-south flightlines spaced 1.6 km (1.0 mi) apart (west half) and 1.2 km (0.75 mi) apart (east half) and from an altitude of 300 m (1,000 ft) above ground level. The aeromagnetic data were first released at 1:63,360 scale in 1975-1976 and subsequently compiled as a 1:250,000-scale aeromagnetic map of the southwestern Brooks Range by the Alaska Division of

Geological and Geophysical Surveys (Hackett, 1977). Rugged topography and marginal weather conditions within the southwestern Brooks Range caused the surveying aircraft to diverge from the nominal flight altitude over some areas within the Ambler River quadrangle. For this reason, magnetic anomalies that have some appreciable or suspected topographic expression are noted on the interpretation maps.

A magnetic-lineament and anomaly-trend map (sheet 2) was prepared to assist in the geologic interpretation of the aeromagnetic data. Major lineaments exist and indicate that regional discontinuities in the magnetic rocks correlate with the gross geologic pattern and structural setting within the Ambler River quadrangle. Magnetic anomaly patterns coincide in part with many individual geologic terranes and assist in defining some of the bedrock geology at depth.

The geologic interpretation map (sheet 3) of the aeromagnetic data identifies major magnetic-lithologic units, their suspected strike and dip, and their relative strength of magnetization. The magnetic-lithologic units were assigned to individual anomalies and magnetic gradient changes on the basis of correlation with the known geology. The units were integrated from a spectrally colored copy of the aeromagnetic map, from the lineament and anomaly-trend map, from detailed and generalized geologic maps (Pessel and Brosgé, 1977; Mayfield and Tailleux, 1978), and from geologic observations and field notes by Fritts, 1969-1972, Pessel, 1972-1975, and Hackett, 1975-1978. Continuous zones of steepened magnetic gradients and abrupt truncation of magnetic anomalies and trends are interpreted as major discontinuities (faults, unconformities, or facies changes) that may have surface expression.

In addition to the magnetic-lithologic units, six major aeromagnetic terranes (fig. 6) are outlined according to characteristic regional anomaly patterns: the Kobuk lowlands, Jade Mountains-Cosmos Hills-Angayucham Mountains, Ambler lowland, southern Brooks Range schist belt, plutonic belt, and thrust belt. The Kobuk lowlands terrane is characterized by broad magnetic-anomaly patterns which indicate considerable and varied depth to magnetic basement. Localized high-intensity anomalies over the Waring Mountains in the southwest corner of the quadrangle may be caused in part by tilted east-trending

mafic-ultramafic rocks that are overlain by Cretaceous clastic rocks. The Jade Mountains-Cosmos Hills-Angayucham Mountains terrane is characterized by sharp, high-amplitude anomalies related to south-southwestward-dipping slabs of mafic and ultramafic rocks. The Ambler lowlands terrane is characterized by a linear zone of nearly flat magnetic gradient which outlines a topographic depression. The northern boundary of this terrane in the eastern part of the quadrangle is formed by the Ambler magnetic lineament, which parallels the conjectural Kobuk fault zone (Grantz, 1966; Patton, 1973). The southern Brooks Range schist belt terrane is characterized by subdued and variable response. Anomalies with variable amplitudes of less than 40 gammas occur with irregular distribution over the metavolcanic rocks of the volcanogenic copper belt. A narrow, composite zone of high magnetic relief is associated with the Walker Lake lineament, a major fault or unconformity. Convergence of the Walker Lake lineament and the Ambler magnetic lineament may reflect a western plunge of the Kalurivik arch, a major anticlinal feature in the southeast part of the quadrangle. The plutonic belt terrane is characterized by low-amplitude anomalies over carbonate rocks and schist broken by large asymmetric negative anomalies associated with granitic plutonic rocks. High-intensity magnetic zones near granite contacts may be over contact aureoles. The thrust belt terrane is characterized by subdued magnetic signature with a few zones of large positive magnetic anomalies over possible mafic rocks or magnetite-rich chloritic schists in the Cutler River area.

The aeromagnetic anomalies, trends, and lineaments in the Ambler River quadrangle are believed to help outline the regional tectonic trends and assist in synthesizing the bedrock geology. Local magnetic anomalies, caused by bedrock exposures of magnetic rock units, are commonly underlain throughout the quadrangle by larger magnetic bodies and are appreciably influenced by the magnetism of the adjacent terranes. These anomalies represent composite sets of juxtaposed magnetic boundaries which complicate geologic interpretation. However, the regional aeromagnetic data do help to define some of the bedrock geology at depth, identify previously unmapped structural features, and aid in projecting suspected trends of mineral deposits.

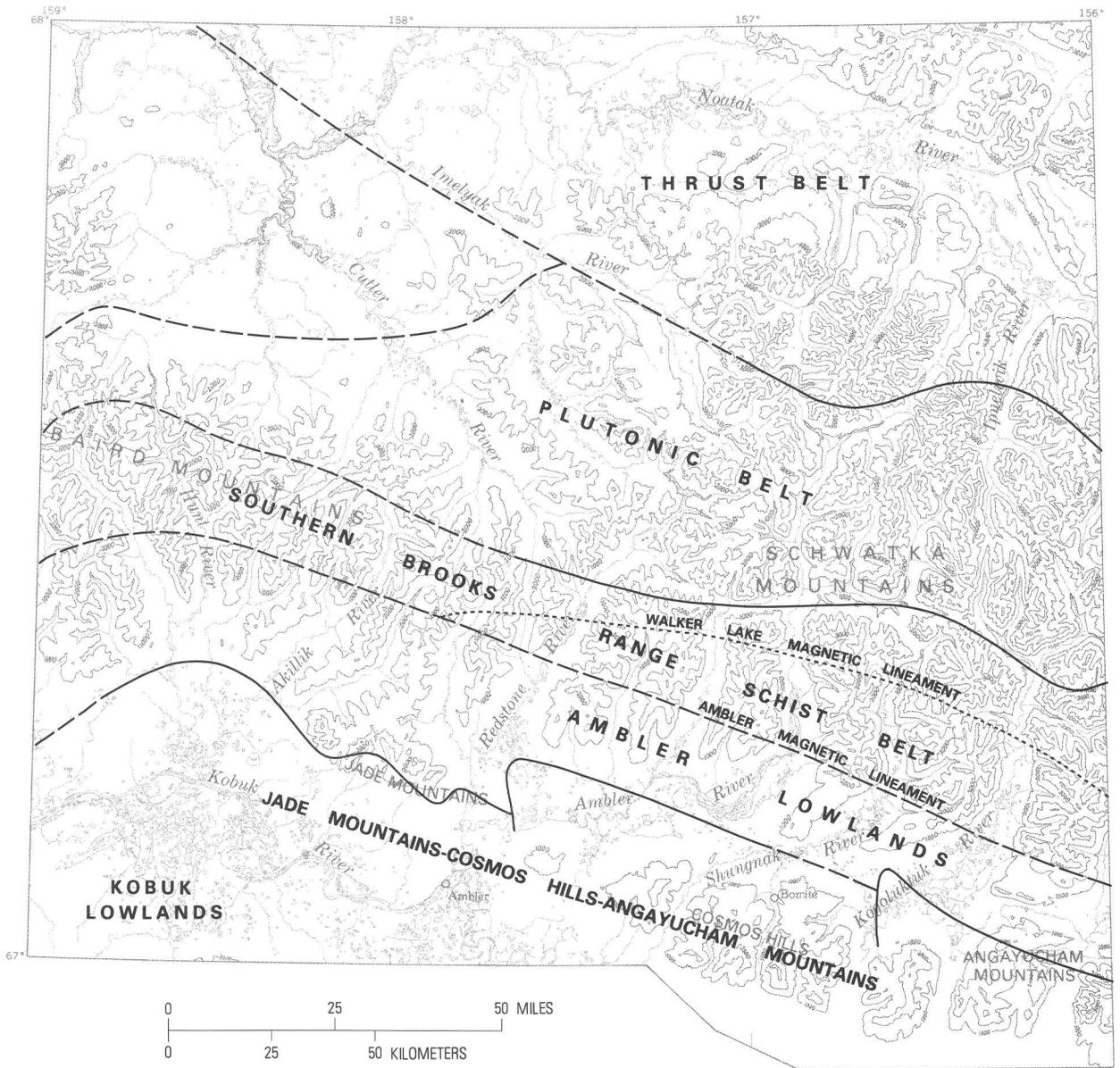


FIGURE 6.—Aeromagnetic terranes of the Ambler River quadrangle and the northeastern part of the Shungnak quadrangle.

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