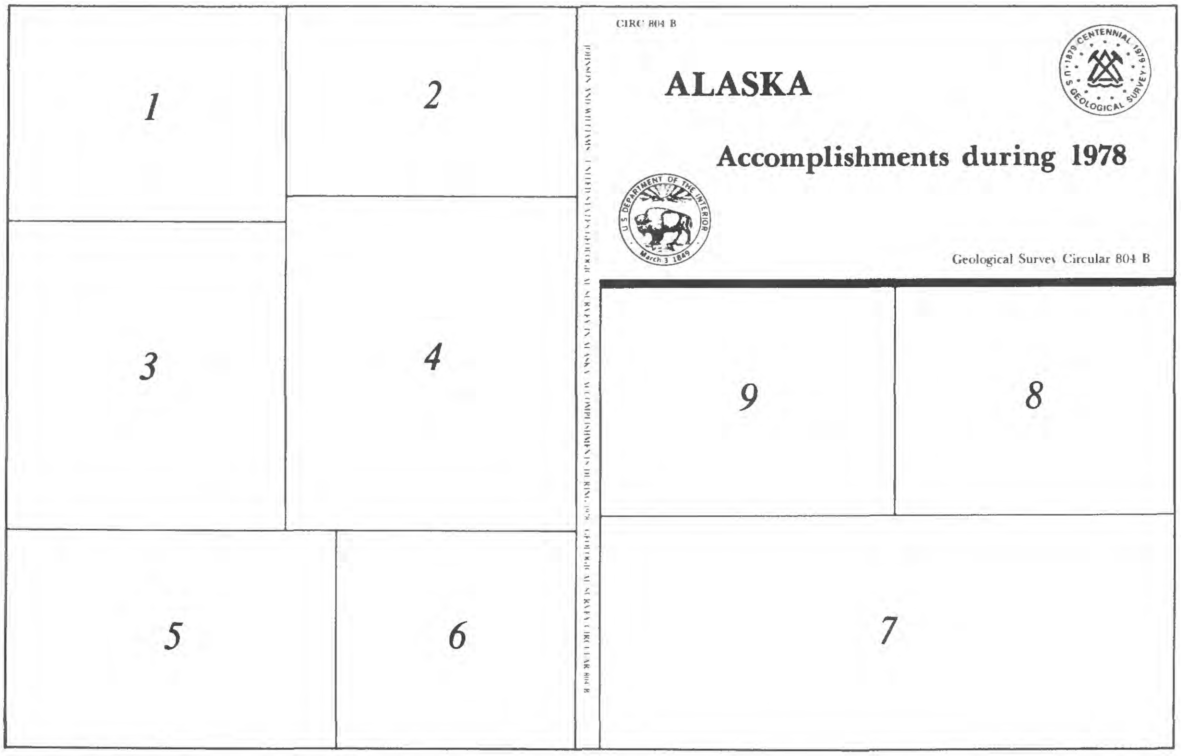
IRC 804-B

ALASKA

Accomplishments during 1978

Geological Survey Circular 804-B



1. USGS camp at mouth of Nation River, July 4, 1902. (A. J. Collier)
2. Icing the runner of a sled, arctic Alaska, ca. 1910. (E. de K. Leffingwell)
3. Topographer at work at plane table, no date. (R. H. Sargent)
4. Walter C. Mendenhall in Alaska, 1898. (A. H. Brooks)
5. Natives building rafts at Camp August 21, lat 61°41′N., long 157°2′W., 1914. (P. S. Smith)
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8. Roberts and Fitzgerald starting on a backpacking trip to the Muklung Hills, August 31, 1935. (J. B. Mertie, Jr.)
9. D. A. Brew in Glacier Bay National Monument, Alaska, July 27, 1977. (B. R. Johnson)

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The United States Geological Survey in Alaska: Accomplishments during 1978

Kathleen M. Johnson and John R. Williams, Editors

GEOLOGICAL SURVEY CIRCULAR 804-B

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ABSTRACT

United States Geological Survey projects in Alaska study a wide range of topics of economic and scientific interest. Work done in 1978 includes contributions to economic geology, regional geology, stratigraphy, engineering geology, hydrology, and marine geology. Many maps and reports covering various aspects of the geology and mineral and water resources of the State were published in 1978.

SUMMARY OF IMPORTANT RESULTS

INTRODUCTION

Significant new scientific and economic geologic information has resulted from many topical and field investigations of the Geological Survey in Alaska during 1978. Discussions of the findings, or, in some instances, narratives of the course of the investigations are grouped in eight subdivisions corresponding to the six major onshore geographic regions (fig. 1), the offshore projects, and projects that are statewide in scope.

STATEWIDE PROJECTS

Mineral resources of Alaska
By Edward H. Cobb

Products of this office project during 1978 were open-filed summaries of references to mineral occurrences (other than mineral fuels and construction materials) in 16 quadrangles (scale 1:250,000) in Alaska (Cobb, 1978b–n) and an open-filed list of recent Federal and State of Alaska reports on the geology and mineral resources of Alaska indexed by quadrangle (Cobb, 1978a). Reference summaries for 61 quadrangles have been released since 1975 (fig. 1).

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——1978b, Summary of references to mineral occurrences (other than mineral fuels and construction materials) in the Beaver, Bettles, and Medfra quadrangles, Alaska: U.S. Geological Survey Open-File Report 78–94, 55 p.

——1978c, Summary of references to mineral occurrences (other than mineral fuels and construction materials) in the Bradfield Canal quadrangle, Alaska: U.S. Geological Survey Open-File Report 78–922, 97 p.

——1978d, Summary of references to mineral occurrences (other than mineral fuels and construction materials) in the Craig quadrangle, Alaska: U.S. Geological Survey Open-File Report 78–869, 261 p.

——1978e, Summary of references to mineral occurrences (other than mineral fuels and construction materials) in the Dixon Entrance quadrangle, Alaska: U.S. Geological Survey Open-File Report 78–863, 33 p.

——1978f, Summary of references to mineral occurrences (other than mineral fuels and construction materials) in the Healy quadrangle, Alaska: U.S. Geological Survey Open-File Report 78–1062, 112 p.

——1978g, Summary of references to mineral occurrences (other than mineral fuels and construction materials) in the Juneau quadrangle, Alaska: U.S. Geological Survey Open-File Report 78–374, 155 p.

——1978h, Summary of references to mineral occurrences (other than mineral fuels and construction materials) in the Mount Fairweather and Skagway quadrangles, Alaska: U.S. Geological Survey Open-File Report 78–316, 128 p.

——1978i, Summary of references to mineral occurrences (other than mineral fuels and construction materials) in the Nome quadrangle, Alaska: U.S. Geological Survey Open-File Report 78–93, 213 p.

——1978j, Summary of references to mineral occurrences (other than mineral fuels and construction materials) in the Petersburg quadrangle, Alaska: U.S. Geological Survey Open-File Report 78–870, 52 p.

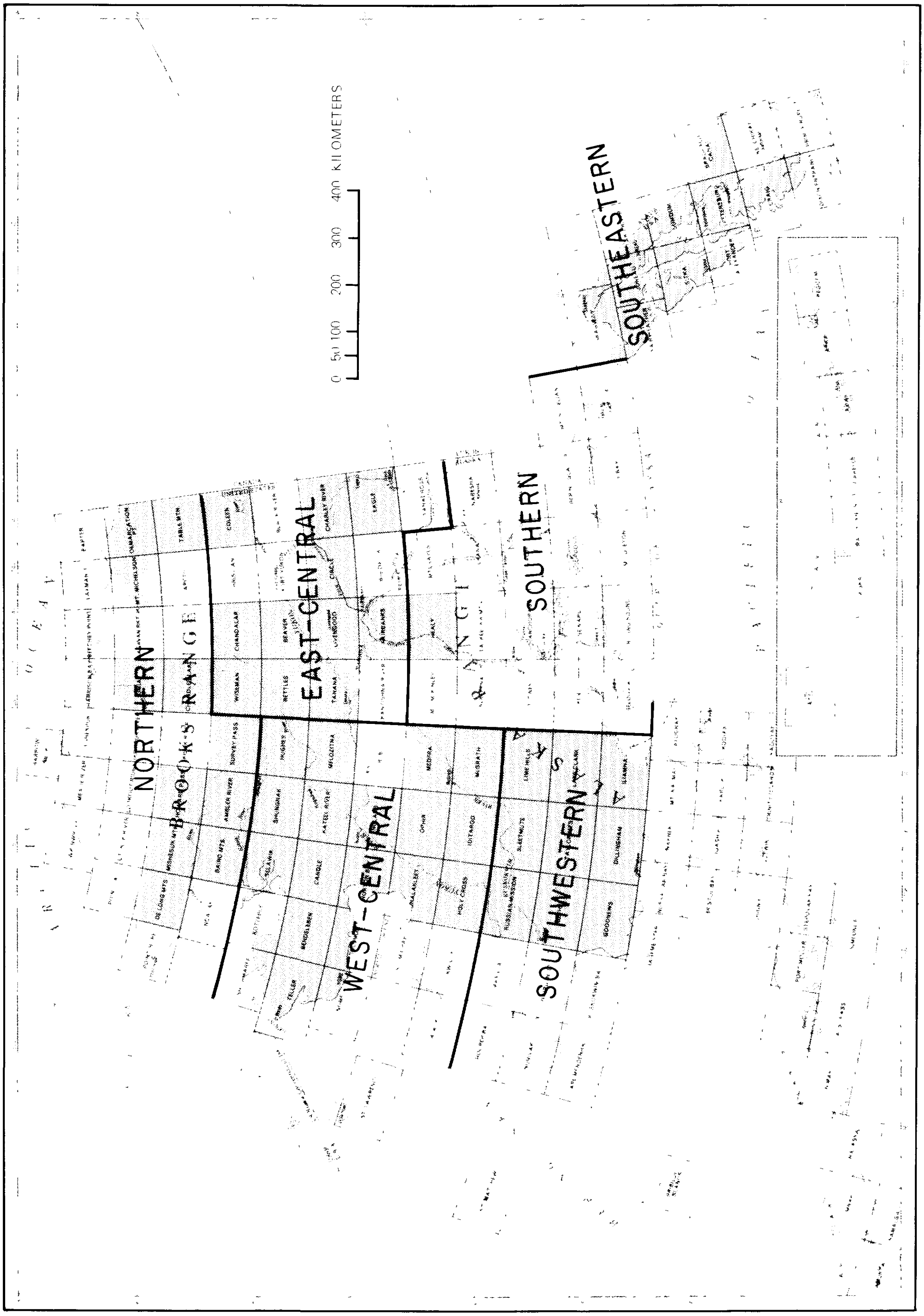

FIGURE 1.—Regions of Alaska used in this report showing quadrangles covered by open-filed reference summaries (shaded), Mineral Resources of Alaska project, 1975–78.

——1978k, Summary of references to mineral occurrences (other than mineral fuels and construction materials) in the Port Alexander quadrangle, Alaska: U.S. Geological Survey Open-File Report 78–787, 32 p.
——1978l, Summary of references to mineral occurrences (other than mineral fuels and construction materials) in the Sitka quadrangle, Alaska: U.S. Geological Survey Open-File Report 78–450, 123 p.
——1978m, Summary of references to mineral occurrences (other than mineral fuels and construction materials) in the Solomon quadrangle, Alaska: U.S. Geological Survey Open-File Report 78–181, 185 p.
——1978n, Summary of references to mineral occurrences (other than mineral fuels and construction materials) in the Sumdum and Taku River quadrangles, Alaska: U.S. Geological Survey Open-File Report 78–698, 64 p.

Landsat color mosaic of southeastern Alaska

By Wm. Clinton Steele, James R. Le Compte, and Nairn R. D. Albert

A controlled 1:1,000,000-scale, standard false-color (bands 4, 5, and 7) Landsat mosaic of southeastern Alaska has been constructed using 14 scenes taken by Landsat 1 and Landsat 2. The mosaic was designed to be compatible with an existing mosaic of mainland Alaska (Albert and others, 1978) as an additional sheet. The mosaic is on a Lambert conformal projection and copies are available to the public in a variety of product types and scales. Details on the coverage, cost, scale, product types, and procedure for ordering the southeastern Alaska mosaic sheet and the mainland mosaic sheets can be obtained from the EROS Data Center, U.S. Geological Survey, Sioux Falls, South Dakota 57198.

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Landsat data interpretation for various AMRAP quadrangles, Alaska

By Wm. Clinton Steele, James R. Le Compte, and Nairn R. D. Albert

Landsat images of the Philip Smith Mountains (Le Compte, 1979), Talkeetna Mountains (Steele and Le Compte, 1978), Ketchikan-Prince Rupert (Steele and Albert, 1978), Big Delta (Albert and Steele, 1978), Seward (J. R. Le Compte, unpub. data, 1978), Survey Pass (J. R. Le Compte, unpub. data, 1978), Ambler River (Albert, 1978), Chignik-Sutwik Island (W. C. Steele, unpub. data, 1978), Lake Clark (W. C. Steele, unpub. data, 1978), and Valdez (J. R. Le Compte, unpub. data, 1978) quadrangles were analyzed as part of the Alaska Mineral Resources Assessment Program (AMRAP) during 1978. These studies, in conjunction with earlier AMRAP investigations, form a substantial data base from which some definitive statements can be made regarding the geologic significance of observed Landsat features. The areas were subjected to interpretive techniques including visual analyses of various computer- and noncomputer-enhanced color and black and white images (most of which are available from the EROS Data Center, Sioux Falls, South Dakota) and computer analyses of the visually interpreted data.

That lineaments detected on Landsat images commonly reflect fracture zones is particularly well shown in the Ketchikan quadrangle. Only a few, perhaps 1 to 10 percent, of the lineaments are faults, and many faults that are mappable at 1:250,000-scale can be detected on Landsat images. Extensions beyond the terminations of many faults mapped by field methods are evident on the imagery.

Lineaments in Alaska can generally be divided into three scales of features: 1) statewide lineament trends (NE, NW, N, and E) (Lathram and Raynolds, 1977), corresponding to the regmatic shear pattern, which not only transect tectonic and stratigraphic boundaries, but also coincide with several of these boundaries; 2) regional trends, such as the lineament set along the Denali fault in the Talkeetna quadrangle or along the Coast Range megalineament in the Ketchikan quadrangle; and 3) local trends which are commonly restricted to specific terranes and various local geologic phenomena or to structures caused by unknown tectonic events.

Circular and arcuate features detected on Landsat images of Alaska can generally be divided into two groups. One group consists of features larger than 50 km in diameter, such as several circular features in the eastern Brooks Range. Few logical explanations have been found for features this large. The other group consists of circular and arcuate features smaller than 50 km in diameter. Approximately 50 percent of these smaller features can be spatially related to known geologic features. These smaller features can be divided into three groups: 1) concentric ("nested") circular features related to batholiths and plutons; 2) solitary circular features related to batholiths, plutons, volcanic cones, craters, and calderas; and 3) "nested" arcuate features related to folds.

Of the Landsat products currently available, the best images for the identification of lineaments and circular and arcuate features are low sun angle black and white images, computer-enhanced first derivative images, and standard false-color images (both computer enhanced and optically enhanced). Computer-enhanced simulated natural color images are the most useful products for identification of iron-oxide-colored areas. Sinusoidally stretched false-color images are best for distinguishing features in relatively flat terrain where shadows and sun angle are not factors and features in areas with small variations in spectroreflectance values and for differentiating between photogeologic terrains.

Within a 1:250,000-scale quadrangle, observed Landsat features coincide with only one or two sites having significant mineralization. Therefore AMRAP-type studies of 1:250,000-scale quadrangles using Landsat data require a regional analysis of areas adjacent to the quadrangle. Relations deduced from these broader scope investigations can then be extrapolated back to Landsat-detected features within the quadrangle.

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Reconnaissance geochemical studies in Alaska

By G. C. Curtin, W. D. Crim, H. D. King, E. F. Cooley, C. L. Forn, J. D. Hoffman, R. M. O'Leary, and R. B. Tripp

A number of previously unreported areas of possible mineral occurrences have been outlined during reconnaissance geochemical studies made in 1978. During the 1978 field season, approximately 6,600 samples were collected by Branch of Exploration Research geochemists in six 1:250,000-scale quadrangles: Chignik, Lake Clark, Medfra, Petersburg, Survey Pass, and Sutwik Island. The main sample media collected were minus-80-mesh stream sediment, heavy-mineral concentrates of stream sediment, and rocks. Other sample media collected in several of the quadrangles included stream water and vegetation. In addition, approximately 4,500 samples of stream sediment and rocks were collected by Alaskan Branch geologists in various parts of Alaska. More than 7,000 of these samples were analyzed for as many as 32 elements in the Anchorage laboratory and in mobile laboratories stationed in Juneau.

Several areas of mineralized rock are outlined in the western part of the Lake Clark quadrangle by anomalously high values of gold, silver, and tin in heavy-mineral concentrates of stream sediment. These anomalous values suggest the presence of possible economic gold placer deposits similar to those in the Bonanza Hills in the north-central part of the quadrangle.

Anomalously high copper and molybdenum values in heavy-mineral concentrates outline several mineral targets in the southeastern and east-central parts of the quadrangle. The most notable area is in the vicinity of the confluence of the North Fork with the Tlikakila River near the east edge of the quadrangle. Concentrate samples from this area contained chalcopyrite, powellite, and molybdenite; these minerals appear to be the most likely source of the high copper and molybdenum values. The chalcopyrite and molybdenum minerals are probably derived from mineralized zones in the intrusive rocks, which range in composition from granite to quartz monzonite (Reed and Lanphere, 1973).

In the Medfra quadrangle mineralized localities in the Mystery Mountains and south of the Sunshine Mountains, in the central and west-central parts of the quadrangle, are outlined by anomalous amounts of arsenic, bismuth, copper, gold, lead, silver, and tin in heavy-mineral concentrates of stream sediments. These localities are underlain by Cretaceous sedimentary rocks, which are intruded by abundant Tertiary felsic hypabyssal dikes and sills, and lie in a belt of Tertiary granitic plutons. The anomalous values may indicate the presence of economic mineral deposits related to the intrusive rocks. Other mineralized localities in the Medfra quadrangle, only partially outlined at this time, include an area about 24 km northeast of the Cripple Creek Mountains in the northwest part of the quadrangle and an area in the Cloudy Mountains in the southwest part of the quadrangle. These localities will be further outlined by geochemical investigations during 1979.

Several uranium-rich areas were revealed in the Talkeetna quadrangle (central Alaska Range) by the results of uranium and thorium analyses made on samples collected during earlier studies. High uranium and thorium values in stream sediment and heavy-mineral concentrates of stream sediment (Curtin and others, 1979) are associated mainly with early Tertiary biotite and biotite-muscovite granite plutons of the McKinley sequence (Reed and Nelson, 1977). Small euhedral grains in the heavy-mineral concentrate samples were identified as uraninite by X-ray diffraction. The anomalous values outline areas that merit further investigation for possible economic mineral occurrences.

Samples of black spruce (*Picea mariana* B.S.P.) and ground birch (*Betula rotundifolia* Sarg.) collected during 1974 geochemical studies in the Yukon-Tanana Upland of east-central Alaska were analyzed to determine their usefulness in geochemical exploration. The results indicate that, at a density of one site per 10 to 25 km^2, the black spruce samples provide useful data for outlining areas rich in silver, copper, molybdenum, boron, nickel, and cobalt. Likewise, ground birch samples furnish useful information for cadmium, molybdenum, lead, and boron.

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Status of regional heat-flow studies in Alaska

By L. A. Lawver, Arthur H. Lachenbruch, and T. H. Moses, Jr.

The Geothermal Studies Project of the Office of Earthquake Studies has collected thermal gradient measurements in holes of opportunity in Alaska during the past 20 years. Initially, the heat-flow work in Alaska was undertaken primarily to understand the thermal regime of permafrost and the related engineering problems associated with construction and petroleum exploration (Lachenbruch and others, 1962). Our greater emphasis now is on collecting data for a better understanding of the tectonics of Alaska and the geothermal potential of any high thermal gradients found. We have obtained thermal gradient measurements from 83 drill holes in 52 different locations (fig. 2). North of the Brooks Range, 40 measurements were made, most of which show relatively uniform thermal gradients. The North Slope holes range in depth from 150 to more than 2,000 m; most are 500 to 750 m deep. With two exceptions, Cape Thompson (Lachenbruch and Marshall, 1969) and the Lisburne site, all the North Slope measurements were made in holes drilled for oil and gas exploration. Temperature has been measured in most of the holes that are still open in the National Petroleum Reserve in Alaska (NPRA), and in 19 of the holes drilled at Prudhoe Bay. Limited thermal conductivity data on cores are available for a few of the Prudhoe Bay holes and most of the older holes in NPRA,

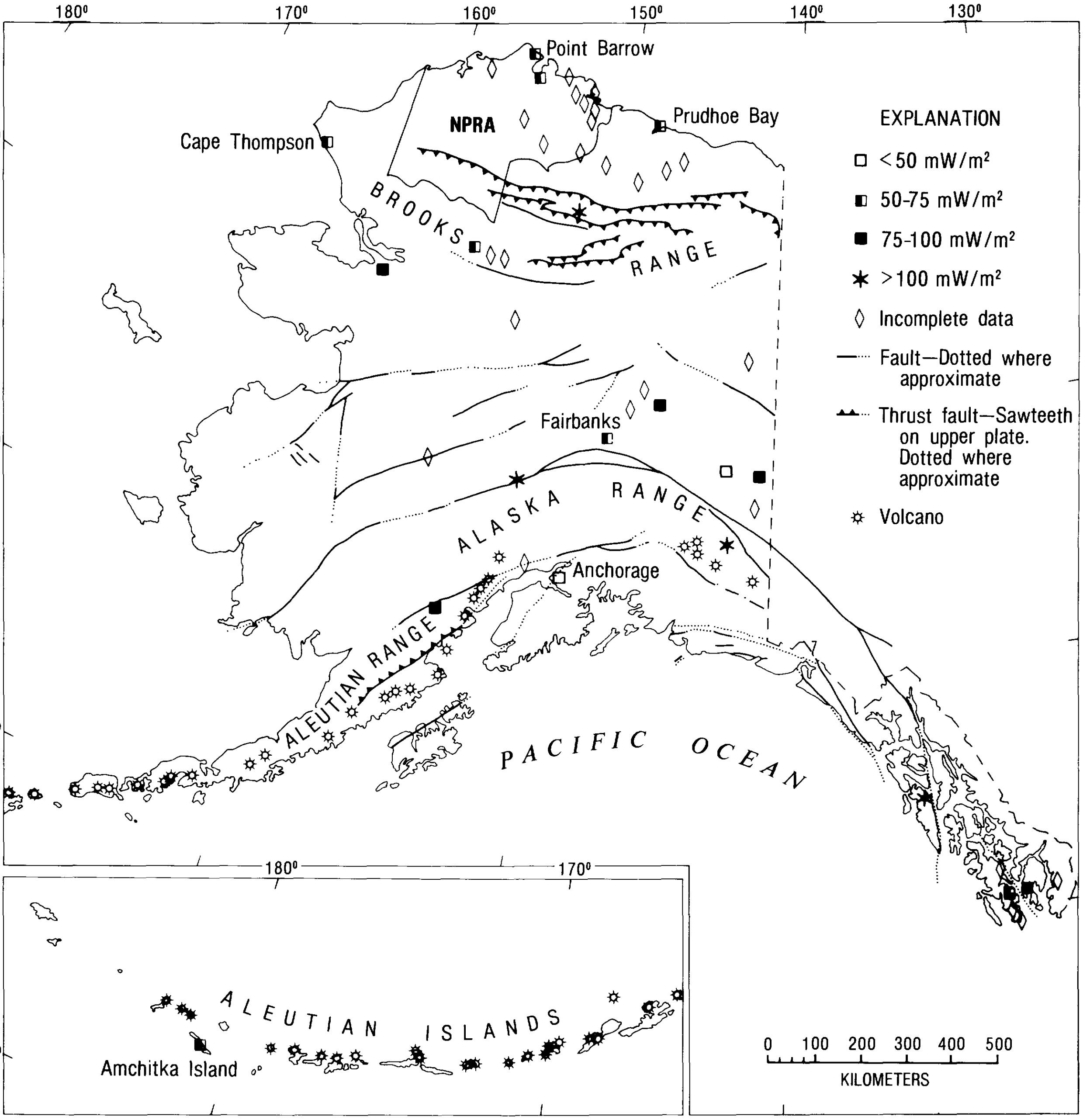

FIGURE 2.—Heat-flow sites in Alaska. NPRA, National Petroleum Reserve in Alaska.

but from none of the recent holes in NPRA. Tentative heat-flow values have been computed for nine different locations north of the Brooks Range. The heat-flow values are reasonably consistent and are in the range of 50–75 milliwatts/m^2 (mW/m^2) for all the North Slope sites except for the Lisburne site, a hole drilled for experiments run by the Lawrence Livermore Laboratory. It has a high heat-flow value that is not readily explainable.

South of the Brooks Range are measurements at 30 different sites, 7 in southeastern Alaska and 1 on Amchitka Island (Sass and Munroe, 1970). Most have been drilled in connection with mining exploration activity or for federally financed experiments. They range in depth from less than 100 m to a 3,100-m hole at Eielson Air Force Base, near Fairbanks; most are less than 200 m deep. Sixteen locations of thermal gradient measurements in Alaska south of the Brooks

Range cannot be assigned heat-flow values because they have no associated conductivity measurements, they do not define reasonably uniform gradients, or they have only recently been collected. Many values in the southern part of the State need to be corrected for extreme topographic relief. The general trend seems to be toward higher values in the Alaska Range, and some high values are found in southeastern Alaska as well. The most reliable heat-flow value was determined for a hole at Eielson Air Force Base where temperature measurements were made every 3 m to a depth of 3,100 m. In addition, 21 conductivity measurements and 85 heat-generation measurements were made. The heat flow at Eielson Air Force Base is approximately 90 mW/m^2. Two low values were measured near Anchorage, both less than 50 mW/m^2.

Although temperatures have been measured in 83 separate holes, they are inadequate for a general understanding of the regional trends of heat flow in such a tectonically complex region as Alaska. Many more heat-flow values in Alaska will be needed before we can begin to have an understanding of the thermal history of the crust and the potential of any specific regions in the state as geothermal resource areas.

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Glacier inventories

By Austin Post and M. F. Meier

The total area of glaciers in the 12 main mountain systems of Alaska is estimated at 74,700 km^2. The area of glaciers in individual mountain massifs was measured by correcting the glacier outlines on 1:250,000-scale maps using recent aerial photographs for control. This method could not be used for the Seward Peninsula nor for the Kilbuk-Wood River Mountains because of inadequate maps and photographs. The mountain regions containing the greatest areas of glacier ice are the Chugach Mountains (21,600 km^2), Alaska Range (13,900 km^2), Saint Elias Mountains (11,800 km^2), and Coast Mountains (10,500 km^2). Individual glacier inventories in regions such as these will be very difficult because some glaciers are bounded in part by obscure or constantly changing ice divides, some consist of variously named component areas, and some span political boundaries.

FIGURE 3.—Okpilak Glacier, Brooks Range. Naled (aufeis) patch at terminus is typical of larger glaciers in this area. U.S.G.S. photograph 74M5–169, by L. R. Mayo, September 10, 1974.

A glacier-by-glacier inventory of the Brooks Range was performed using preliminary copies of 1:63,360-scale topographic maps; glacier margins were checked or reinterpreted by comparison with aerial photographs. In this study, 1,001 glaciers were identified and measured, the area of exposed ice was 647 km^2, and the total area (exposed plus moraine-covered ice) was 723 km^2. Individual glaciers were found to range in area from 0.03 km^2 to 16.8 km^2 (Okpilak Glacier, fig. 3) and to have a mean area of 7.23 km^2.

Thrust sequences in the Misheguk Mountain quadrangle, Brooks Range, Alaska

By Inyo Ellersieck, C. F. Mayfield, I. L. Tailleur, and S. M. Curtis

The Misheguk Mountain quadrangle is located in the eastern De Long Mountains of the western Brooks Range. Reconnaissance mile-to-the-inch mapping in the south half of the quadrangle, currently being compiled by the authors, documents large-scale thrusting mapped and reported previously (Tailleur and others, 1966; Tailleur and Snelson, 1966; Martin, 1970).

The structure of the region is dominated by thrust sheets tens of kilometers in lateral extent that have moved relatively northward over one another. Each thrust sheet is characterized by a succession of rocks ranging in age from Late Devonian to Early Cretaceous, which can be distinguished by lithology from coeval rocks in the other sheets. The thrust sheets appear to have been superposed in an orderly fashion; despite later deformation, "lower" sheets are seldom observed structurally above "upper" sheets.

The package of rocks in each thrust sheet is herein called a thrust sequence. Composite stratigraphic columns of seven thrust sequences mapped in the Misheguk Mountain quadrangle are shown in figure 4. For the sake of simplicity, stratigraphic units of questionable affinity have been included in thrust sequences four and five. The sequences are numbered in structural order, with number one being the lowest and seven being the highest.

The present superposition of thrust sequences has important palinspastic implications because the coeval rocks in each sequence must have been deposited side by side. The minimum crustal shortening necessary to have moved them into their present vertical succession is approximately 250 km. Outcrops of rocks of Mississippian to Permian age south of the quadrangle may be continuous with the autochthonous sequence of Paleozoic and Mesozoic rocks under the North Slope (Mull and Tailleur, 1977). If this sequence underlies the Misheguk Mountain quadrangle at depth, the amount of crustal shortening is increased by at least 125 km. If the root zone for the ophiolitic rocks of sequences six and seven is on the south edge of the Brooks Range (Patton and others, 1977), then another 125 km of shortening is added, for a total of about 500 km. Folding and thrust faulting within the major sheets may increase the total shortening within the Misheguk Mountain quadrangle to as much as 600 km, six times the present width of the thrust belt.

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The Avan Hills ultramafic complex, De Long Mountains, Alaska

By Jay Zimmerman[1] and Paul G. Soustek[1]

The Avan Hills ultramafic complex is one of several large bodies of spatially and genetically related ultramafic and phaneritic intermediate to mafic rocks that occur along a generally east-west line in the De Long Mountains of the western Brooks Range. Roeder and Mull (1978) have suggested that the complexes are ophiolitic klippen that were thrust northward during an obductive orogenic phase in Mesozoic or early Tertiary time. Detailed mapping in the Avan Hills tends to confirm these conclusions.

[1] Southern Illinois University at Carbondale.

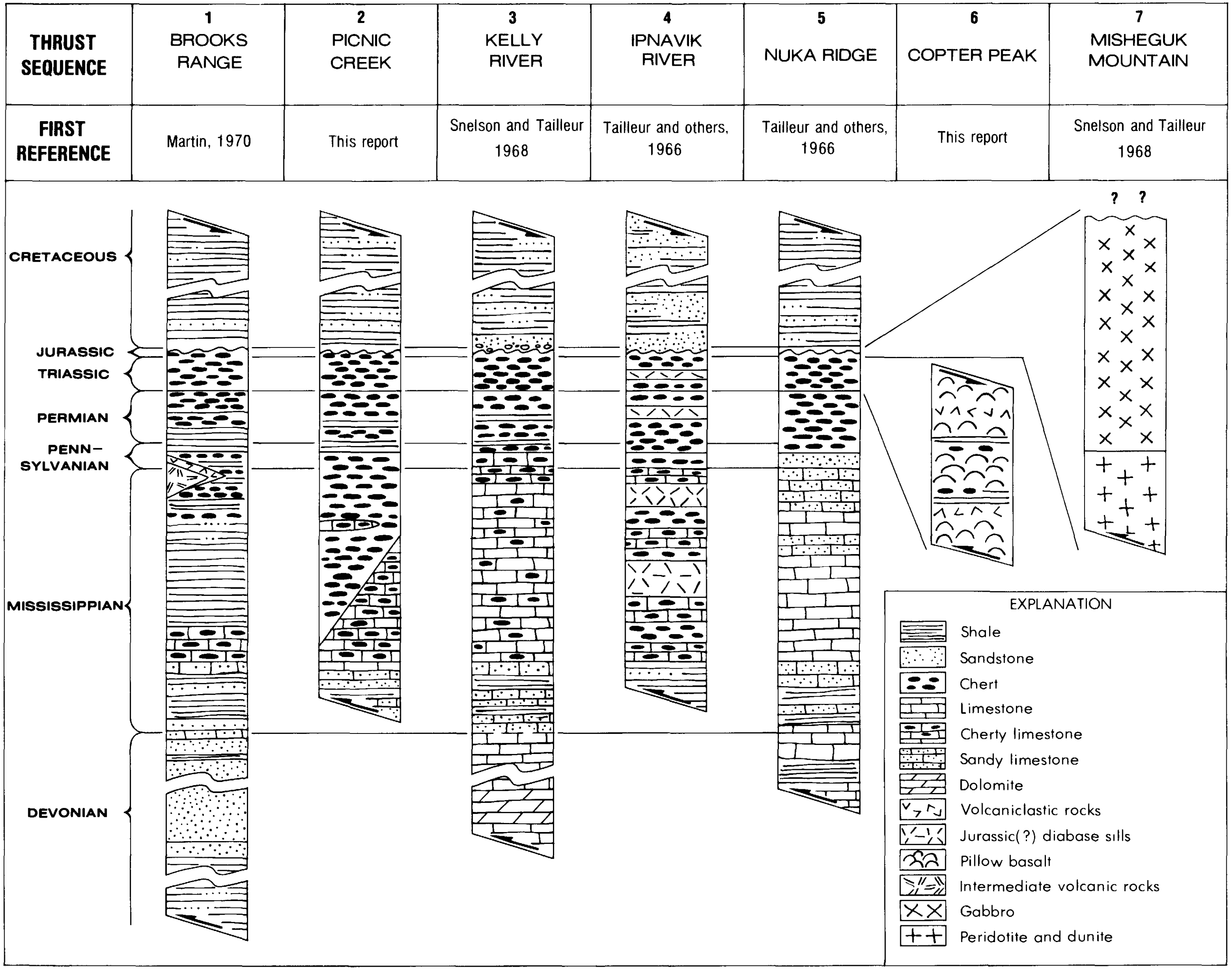

FIGURE 4.—Schematic sections of thrust sequences in Misheguk Mountain quadrangle.

The Avan Hills ophiolite consists of three broad lithologic zones. In ascending order they are 1) a zone of ultramafic tectonites; 2) a transition zone containing both ultramafic and coarse-grained, intermediate and mafic rocks tonites; and 3) a "gabbroic" zone consisting of coarse-grained intermediate and mafic rocks with mesoscopic and microscopic textures ranging from tectonitic to cumulate. Rocks of the complex overlie a sequence of mafic volcanic material along a thrust contact. At present, there is no evidence that the volcanic rocks are genetically related to the overlying ultramafic units.

The ultramafic zone consists of interlayered dunite, harzburgite, and pyroxenite; the pyroxenite is volumetrically minor except near the base of the transition zone. Boundaries between dunite and other compositional layers are generally sharp, but contacts between peridotite and pyroxenite are typically gradational. A nearly ubiquitous mesoscopic foliation in all three rock types is defined by flattened or rotated grains of orthopyroxene and (or) chrome spinel. Foliation planes are typically parallel or subparallel to compositional layering. Cross-cutting relations are limited to local pyroxenite dikes and, in the lower parts of the zone, to thin, dikelike segregations of dunite that transect both foliation and layering. At one location linear trains of chrome spinel grains are continuous from peridotite across dunite "dikes," evidence suggesting that the "dikes" may be the result of selective removal of pyroxenitic material along irregular planes. Tight, mesoscopic folding of thin peridotite and chrome spinel layers is locally common, and there is evidence of open, macroscopic folding over much of the zone.

On a microscopic scale, both dunite and peridotite show evidence of considerable plastic strain and recrystallization. Coarse, heavily kinked, relict olivine grains in both rock types range from about 1.5 to 6.0 mm in long dimension, although crystals as long as 20 mm are present in some rocks. The presence of both strained and unstrained interstitial neoblasts is typical. Orthopyroxenes are bent, embayed, and locally recrystallized. Spinel with subhedral to rounded outlines is distributed along olivine and orthopyroxene grain boundaries or is included within olivine crystals. The textures of the five samples examined to date conform to the protogranular, porphyroclastic, and protogranular-to-porphyroclastic transitional textures described by Mercier and Nicolas (1975). The same textures would be considered porphyroclastic in the classification of Pike and Schwarzman (1977). The presence of rounded spinels enclosed within olivine crystals suggests that the rocks have undergone more than one deformation-recrystallization cycle (Mercier and Nicolas, 1975).

The contact between the ultramafic and transition zones is defined at the first appearance of interlayered, coarsely crystalline intermediate or mafic rocks. These initially occur as isolated layers or lenses in peridotites or pyroxenites and become more commun up-section. Toward the top of the transition zone, volumetric roles are reversed as ultramafic layers occur with decreasing frequency.

A gradational contact more than 5 mm thick was noted between a diorite layer or lens and adjacent peridotite in one sample that was examined in thin section. In this sample, relatively coarse (0.5 to 1.5 mm long), embayed calcic plagioclase grains show abundant evidence of strain, including undulatory extinction and bent twin lamellae. Superimposed along grain boundaries and across parts of the relict grains are sprays of small (0.05 to 0.15 mm long), strain-free, possibly neoblastic feldspars that typically form 120° angles with adjacent grains.

Coarsely crystalline rocks of the "gabbroic" zone, in the vicinity of its basal contact, are gabbro, olivine gabbro, and diorite, characterized by planar preferred orientations of mafic minerals that define a strong foliation. These rocks, as well as those of similar composition in the transition zone, are tectonites. The thickness of the tectonite layer at the base of the gabbroic zone has not been determined, but farther up-section, cumulates become dominant. Considerable evidence for deuteric alteration is found in all rocks from this zone that have been examined to date.

During the 1978 field season no attempt was made to study the upper parts of the gabbroic zone in a systematic manner. Diorite and gabbro are found in numerous Alpine-type ultramafic complexes considered to be ophiolitic. Complete ophiolites, such as the Vourinos ophiolitic Complex (Moores, 1969), contain coarse leucocratic material as well as intermediate to basaltic extrusive rocks. That these constituents have not been found in the Avan Hills ultramafic complex may be due to limited investigations of the gabbroic zone. It is more likely, however, that such rocks, if originally present, have been stripped from the top of the complex during thrust emplacement or by postemplacement erosion.

The composition, structural elements, and texture of rocks of the Avan Hills ultramafic complex indicate that they have been subjected to a complex history of deformation, much of which took place at high temperature and pressure. Most mesoscopic and microscopic features are characteristic of ductile response of the materials to stress and probably originated while the rocks were in a preorogenic environment. Some elements may have developed during synorogenic emplacement. Present evidence of more brittle response during late synorogenic or postorogenic deformation is limited to numerous, small, high-angle faults that occur over much of the complex and systems of closely spaced microfractures with antitaxial serpentine fillings that are present in several samples from the ultramafic zone.

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The Ginny Creek zinc-lead-silver and Nimiuktuk barite deposits, northwestern Brooks Range, Alaska

By C. F. Mayfield, S. M. Curtis, I. F. Ellersieck, and I. L. Tailleur

Two new mineral deposits, the Ginny Creek deposit and the Nimiuktuk deposit, were discovered in the De Long Mountains during geologic mapping in the south half of the Misheguk Mountain quadrangle. The Ginny Creek deposit is located between Trail Creek and the Kugururok River at the head of Ginny Creek. The Nimiuktuk deposit is located 59 km to the east near the upper part of the Nimiuktuk River (fig. 5). Each deposit has received only reconnaissance investigation (Mayfield and others, 1979) owing to the limited amount of time available for field study.

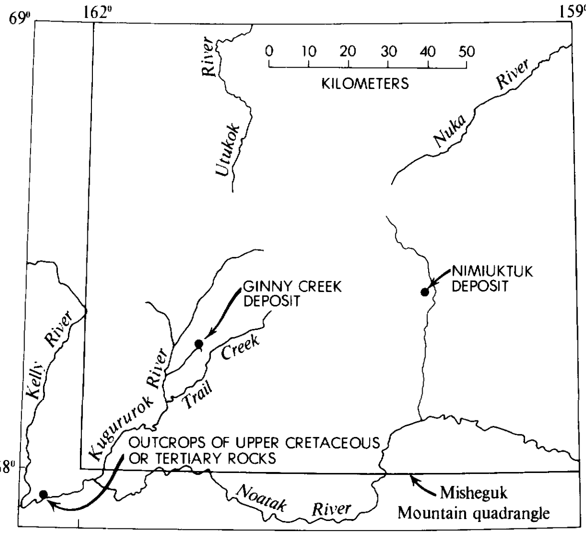

FIGURE 5.—Map showing Misheguk Mountain quadrangle, with locations of Ginny Creek deposit, Nimiuktuk deposit, and outcrops of Upper Cretaceous or Tertiary rocks along the Noatak River.

The most important commodities from the Ginny Creek deposit appear to be zinc and lead from the minerals sphalerite and galena. Silver may also be important; high geochemical values for this element occur in some samples from the deposit. Host rock for the sulfides is sandstone and shale, correlative with the upper part of the Noatak Sandstone and with the limestone at the base of the overlying Kayak Shale. Sphalerite and galena occur mainly as disseminated crystals in sandstone, but outcrops of massive sulfide locally occur at the top of the sandstone section or in the overlying limestone. Quartz veins are minor, and most are barren of sulfides. The most common gangue mineral is siderite, which occurs abundantly in the host rocks throughout the mineralized zone. Pyrite is a minor constituent in the deposit.

The surface area affected by mineralization appears to be large. The main exposure of mineralized rock, which contains some zones of barren sandstone and shale, is at least 900 m long and 600 m wide. It is covered by tundra to the east and west and by the valley of Ginny Creek to the south. To the north, the mineralized sedimentary rocks are covered by younger rocks. A poorly exposed sphalerite-rich gossan in limestone occurs 1 km to the southwest. High zinc and lead values from stream-sediment samples collected in two tributaries indicate probable mineralized rock 1 km to the south of the main zone of disseminated sulfides.

The grade of the deposit is uncertain. Randomly collected samples from surface float in the area where sulfides are disseminated in sandstone indicate grades of from 0.3 to 1 percent zinc with lesser amounts of lead. The samples were collected from leached gossan, and higher grades may be expected at depth. Outcrops of rock containing high-grade massive sulfide locally occur near the top of the sandstone unit and in one place in the overlying limestone. Bedrock is not well enough exposed to show the actual grade or extent of the deposit without applying subsurface methods of evaluation.

The Nimiuktuk deposit underlies a small hill about 7 to 10 m high, 40 m wide, and 60 m long, isolated in the middle of a flat tundra-covered field. The entire hill is composed of cobble- to boulder-size fragments of nearly pure barite. The nearest bedrock, exposed about 500 m to the northeast, consists of Upper Mississippian black shale and chert in contact with Lower Cretaceous shale and wacke. Small rubbly outcrops 600 m to the southwest are Carboniferous(?) volcanic rocks in probable thrust contact with structurally overlying sandy limestone of the Utukok Formation. The volcanic rocks are composed predominantly of feldspar, biotite, and leucoxene (after ilmenite?). Feldspar has been extensively altered to carbonate and phyllosilicate minerals. The absence of quartz in phenocrysts and high percentage of alkalic feldspar suggest a latite or andesite composition similar to the volcanic rocks in the Drenchwater area (Tailleur and others, 1966; Nokleberg and Winkler, 1978).

The age of the host rock for the barite deposit is only speculative because surface exposures in the area are so poor. We suspect that the Nimiuktuk deposit is similar to the Red Dog deposit, where massive barite is believed to have been deposited syngenetically in Upper Mississippian black shale and chert (Plahuta and others, 1978). Unlike the Red Dog deposit, geochemical samples from the watershed of the Nimiuktuk deposit are not high in zinc nor lead.

Mineralization at the Ginny Creek and Nimiuktuk deposits probably occurred at about the same time as at the other major deposits of zinc, lead, and (or) barite in the De Long Mountains. Studies at Red Dog (Tailleur and others, 1977; Plahuta and others, 1978) and at Drenchwater (Nokleberg and Winkler, 1978) indicate that mineralization probably occurred in the Late Mississippian (Early Pennsylvanian?). The host rocks at Ginny Creek, Red Dog, and Drenchwater were probably mineralized under different conditions. At Drenchwater and Red Dog, a sea floor precipitation model seems to best explain many of the sulfide/host rock relations, whereas at Ginny Creek, a subsurface model for deposition of sulfides is indicated. The movement of lead, zinc, and sulfur in both the surface and subsurface strongly suggests that hydrothermal systems were an integral part of the mineralization. The most likely source of heat to produce such systems in the Late Mississippian is the magma(s) that produced the localized occurrences of Upper Mississippian volcanic rocks in the De Long Mountains.

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A new find of Upper Cretaceous or Tertiary sedimentary rocks in the Noatak Valley

By Inyo Ellersieck, I. L. Tailleur, C. F. Mayfield, and S. M. Curtis

Poorly indurated sedimentary rocks, unlike any previously known formations in the center of the Brooks Range, were found in 1978 on the north bank of the Noatak River, 7 km upstream from its confluence with the Kelly River (fig. 5). The outcrop was discovered by Frank Szczepanski, helicopter mechanic. The exposure is truncated by Quaternary gravel near high-water level and is accessible only when the Noatak River is at relatively low flow. Extensive Quaternary cover in the Noatak Valley prevents tracing the rocks away from the river.

The section exposed is about 100 m thick. The lower 50 m was not accessible but appears from a distance to be composed of blue-gray siltstone and claystone. The upper 50 m is composed of approximately 60 percent siltstone and claystone, 35 percent sandstone, and 5 percent conglomerate, dipping 30° to 75° west-southwest.

Finer grained rocks are dominantly clayey siltstone but also include sticky, possibly montmorillonitic, clay. Partings of carbonaceous material in these rocks define planar stratification and ripple marks. Some beds contain rootlets or impressions of plant material and lenses, as thick as 5 cm, of silty and shaly low-rank coal in which flattened branches are visible.

The sandstone is light bluish gray, well sorted, and medium to coarse grained. Most of the sandstone is very poorly indurated and can be crumbled with the fingers, but a few beds from 1 to 3 m thick are cemented by calcite. The grains are subangular to subrounded. They are about 70 percent quartz, 28 percent chert, and less than 1 percent each of plagioclase, mica, and unidentified minerals that have been altered to clay.

Several conglomerate beds 1 to 1.5 m thick occur near the top of the section. The clasts are pebble to cobble size, in a sandy, calcite-cemented matrix. The maximum diameter observed was 15 cm. The clasts consist of graywacke probably from the Okpikruak Formation, quartz arenite probably from the Noatak Sandstone, quartz, and chert from Mississippian through Triassic formations in the area.

Sedimentary structures include channels at the base of sandstone and conglomerate beds, lag concentrations of pebbles in sandstone, crossbedding, and ripple marks. The combination of sedimentary structures, lithology, and coal indicates that the sediments were probably deposited on a river flood plain.

The age of the beds is uncertain. The presence of clasts that are probably from the Lower Cretaceous Okpikruak Formation and the poor induration of the rock relative to the Okpikruak Formation indicate that the beds are of post-Early Cretaceous age, possibly later than the major part of the Cretaceous Brooks Range orogeny. Palynomorphs from several siltstone beds were examined by Hideyo Haga of Anderson, Warren, and Associates, San Diego, California (oral commun., 1979). They are either too poorly preserved to identify or are of undifferentiated Jurassic and Cretaceous age; no Cenozoic forms were observed.

Conceivably, the identifiable forms could have been reworked from older formations, and the rocks could be of Tertiary age. Redeposition of palynomorphs is a common occurrence in Mesozoic rocks on the North Slope. On the basis of the available evidence, the rocks are considered to be of Late Cretaceous or Tertiary age.

The presence of rocks of this age and lithology in the Noatak Valley is significant because it is evidence for a basin of relatively low-density sediments under the lower Noatak River valley to the southwest, which was postulated by Barnes and Tailleur (1970) as the cause of an intense (50-mgal) gravity low. Although this gravity low appears to be closed on the west, the basin may be tectonically related to the mostly Tertiary and perhaps Cretaceous Hope basin (Grantz and others, 1975) under the Chukchi Sea to the west.

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Gamma-ray values in the Misheguk Mountain region and in parts of Barrow, Teshekpuk, and Harrison Bay quadrangles, Alaska

By S. M. Curtis, Richard Rossiter, I. F. Ellersieck, C. F. Mayfield, and I. L. Tailleur

To augment a mile-to-the-inch geologic mapping project in Misheguk Mountain quadrangle in the summer of 1978, a portable scintillometer was carried aboard a Bell 206B[2] helicopter used for field support. Gamma-ray intensities were measured and recorded by Richard Rossiter (helicopter pilot) at landing sites, usually determined by the needs of geologists making field traverses. Intensities were measured primarily with a Mt. Sopris Instrument Co. model SC-132 scintillometer at 704 scattered localities in the southern part of Misheguk Mountain quadrangle and in parts of the adjacent Baird Mountains and Howard Pass quadrangles.

Two areas were found with anomalous gamma-ray intensities. Intensities of about six times background are associated with leucocratic volcanic rocks and tuffaceous sediments on the Kugururok River west of Misheguk Mountain (lat 68°15′ N., long 161°30′ W.). These rocks may be correlative with similar volcanic rocks associated with upper Paleozoic sedimentary rocks and sulfide deposits at Drenchwater Creek in the Howard Pass quadrangle (Nokleberg and Winkler, 1978). Intensities ranging from 14 to 24 times background are associated with black, phyllitic, carbonaceous shale and overlying, lighter colored, schistose siltstone in the Maiyumerak Mountains in Baird Mountains quadrangle (lat 67°12′ N., long 161°35′ W.). These rocks probably occur in the lower, Devonian(?), part of the Endicott Group, but no assessment of the anomalous intensities can be made at this time. These data have been compiled for release in a U.S. Geological Survey Open-File Report.

In September and October of 1978 the same helicopter and scintillometer were used in a sampling program for surficial helium in parts of Barrow, Teshekpuk, and Harrison Bay quadrangles, Alaska (Alan Roberts, oral commun., 1978). Gamma-ray intensities were measured at 544 helium-sample locations, all located on soil cover, which tends to block radiation from underlying bedrock. All measured intensities appear to be background values, and none are anomalous. These data have also been compiled for release in a U.S. Geological Survey Open-File Report.

[2] Any use of trade names is for descriptive purposes only and does not constitute endorsement of these products by the U.S. Geological Survey.

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Siniktanneyak Mountain ophiolite

By Steven W. Nelson, Warren J. Nokleberg, Martha Miller-Hoare, and Michael W. Mullen

Reconnaissance and familiarization visits were made during the summer of 1978 to the Siniktanneyak Mountain ophiolite complex located in the Howard Pass quadrangle, western Brooks Range, Alaska, by Nelson, Miller-Hoare, and Mullen in preparation for detailed petrographic and petrochemical studies. Nokleberg made three detailed traverses along the southwestern margin of the complex as part of structural studies across the western Brooks Range. Additional data were obtained from fixed wing aircraft, helicopter spot stations, and short traverses.

The ophiolitic nature of the rocks at Siniktanneyak Mountain was first recognized by Tailleur (1973) and further described by Roeder and Mull (1977) and by Patton and others (1977). They recognized the reverse structural relation in which the ultramafic/mafic intrusive part of the ophiolite complex structurally overlies pillow basalt and diabase (fig. 6) and discussed the regional tectonic significance of the ophiolites in the western Brooks Range. However, most of the information and interpretations to date are based upon reconnaissance-scale mapping and study. Only the broad features of the ophiolite are now known, and only scant published information is available about the internal structure and petrography.

Recent petrographic observations and new fossil data from the 1978 season are as follows (locality numbers keyed to fig. 6):

A. D. L. Jones (oral commun., 1978) identified Triassic radiolarians from a light- to dark-gray, well-bedded chert spatially

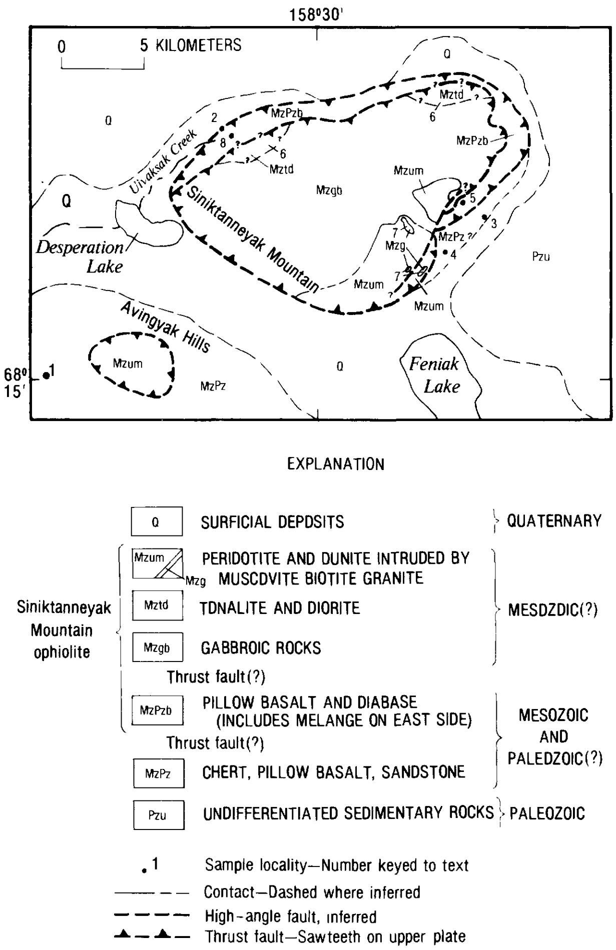

FIGURE 6.—Geologic sketch map of Siniktanneyak Mountain ophiolite, Howard Pass quadrangle.

associated with pillowed volcanic rocks and orange-weathering peridotite in the Avingyak Hills (loc. 1). J. T. Dutro, Jr. (written commun., 1978 and 1979) identified brachiopods of possible Early Permian age from basaltic tuff in an ophiolite melange along Uivaksak Creek (loc. 2), and possible Devonian fossils from sedimentary rocks structurally below pillow basalt (loc. 3) and peridotite (loc. 4) on the east side of the ophiolite complex. Anita Harris (written commun., 1978) identified a middle Famennian to middle Osagean conodont from an 8-m-thick gray limestone lens(?) within a 200-m-thick pillow basalt sequence on the east side of the ophiolite complex (loc. 5). These fossils suggest two possible interpretations for the age of the volcanic rocks structurally underlying the peridotite and gabbro part of the ophiolite complex:

1. Oceanic volcanism occurred from Late Devonian to at least Early Permian time, or
2. The volcanic rocks are younger than the fossiliferous units, which are tectonic inclusions emplaced during obduction of oceanic rocks over a shelflike assemblage.

B. Petrographic examination of thin sections from the cumulate gabbro part of the ophilite complex confirms the heterogeneous composition of the gabbroic rocks that was observed in the field. Cumulate layering alternates from plagioclase-rich layers to pyroxene-rich layers. Using the classification of Streckeisen (1973), gabbro, hornblende gabbronorite, gabbronorite, olivine gabbro, and anorthosite have been identified from the gabbroic part of the ophiolite complex. Locally the gabbroic rocks have been intruded by coarse-grained hornblende-plagioclase dikes. Anhedral olivine grains discontinuously mantled by an inner rim of clinopyroxene and an outer rim of brownish-green hornblende have been observed in olivine gabbro from the western part of the ophiolite complex. Secondary amphibole (actinolite?) replacing pyroxene has been observed in gabbro from the marginal areas of the ophiolite complex and from cataclastic zones within the gabbro.

C. Two distinctive types of felsic intrusive rocks have been observed in the field. Along the northern margin of the ophiolite complex felsic dikes intruding gabbro are apparently related to small felsic plugs or stocks (loc. 6) in this area. These intrusive bodies range in composition from diorite to tonalite, and the characteristic accessory minerals are biotite, hornblende, and clinopyroxene. In addition, most samples contain secondary amphibole (actinolite?) and epidote. The diorite and tonalite may represent late differentiates of the gabbroic magma. The other type of felsic intrusive rock is unaltered muscovite-biotite granite, which has been observed as small intrusive(?) bodies in peridotite from the southeastern part of the complex (loc. 7). These rocks have a well-developed granitic texture, are not granophyric, and contain approximately 25 percent potassium feldspar. Petrochemical studies to be completed next year will help to determine whether these felsic rocks are related to the igneous processes that formed the gabbros or whether they are a separate younger igneous event.

D. Semiquantitative spectrographic analysis of one mineralized sample from a 4-m-wide, orange-weathering, pyrite-bearing feldspathic dike(?) in pillow basalt from the eastern margin of the ophiolite complex (loc. 5) showed 20 ppm silver, 5,000 ppm barium, and 300 ppm copper. At the present time it is not known whether this dike is related to the felsic intrusive bodies discussed in C above or is a separate phase related to the volcanic rocks. Similar appearing sulfide-bearing rocks have been observed in the western part of the ophiolite complex (loc. 8).

Detailed mapping, petrographic observations, and petrochemical studies, including rubidium and strontium isotope studies of the igneous rocks, will provide clues to the origin of the various igneous rocks and the ophiolite complex.

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Tectonic significance of metamorphic grade distribution, Survey Pass quadrangle, Alaska

By Steven W. Nelson and Donald Grybeck

Petrographic examination of more than 1,400 thin sections of middle and upper Paleozoic metasedimentary and meta-igneous rocks from the Survey Pass quadrangle, Alaska, has resulted in recognition of three grades of regionally metamorphosed rocks (fig. 7), ranging from very low grade to medium grade following the terminology of Winkler (1976).

The central core region of the quadrangle contains Middle Devonian granite orthogneiss plutons (Nelson and Grybeck, 1978; Dillon and others, 1979; Silberman and others, 1979) and medium-grade metamorphic rocks. The western part of this region (west of the Reed River fault) contains metamorphic rocks that are transitional from low to medium grade. Outside the central region the metamorphic rocks are generally low grade. Rocks in the northern part of the quadrangle are Upper Devonian clastic rocks, mostly quartz sandstone and shale, with a well-developed penetrative cleavage in the shale but little or no diagnostic metamorphic mineralization. Pillow basalt and flows of the Angayucham Mountains and Helpmejack Hills along the southern boundary of the quadrangle have been subjected to very low grade metamorphism.

Mineral criteria used to classify the rocks into the three grades are:

1. Very low grade: defined by the presence of pumpellyite in pillow basalt and flows.
2. Low grade: defined by the presence of chlorite, muscovite, albite, actinolite, chloritoid, and epidote in metasedimentary and metavolcanic rocks. Retrograded glaucophane is present in the chloritoid-quartz schist belt in the southern part of the quadrangle and indicates an earlier(?) period of high-pressure metamorphism (Turner and others, 1978).
3. Medium grade: defined by the presence of garnet, biotite, plagioclase, muscovite, and amphibole in schist and paragneiss.

Structural relations indicated by regional field mapping (Mull and Tailleur, 1977; Newman and others, 1977) and petrographic observations indicate that the rocks have been involved in at least two metamorphic events. Radiometric dating in this area of the southern Brooks Range

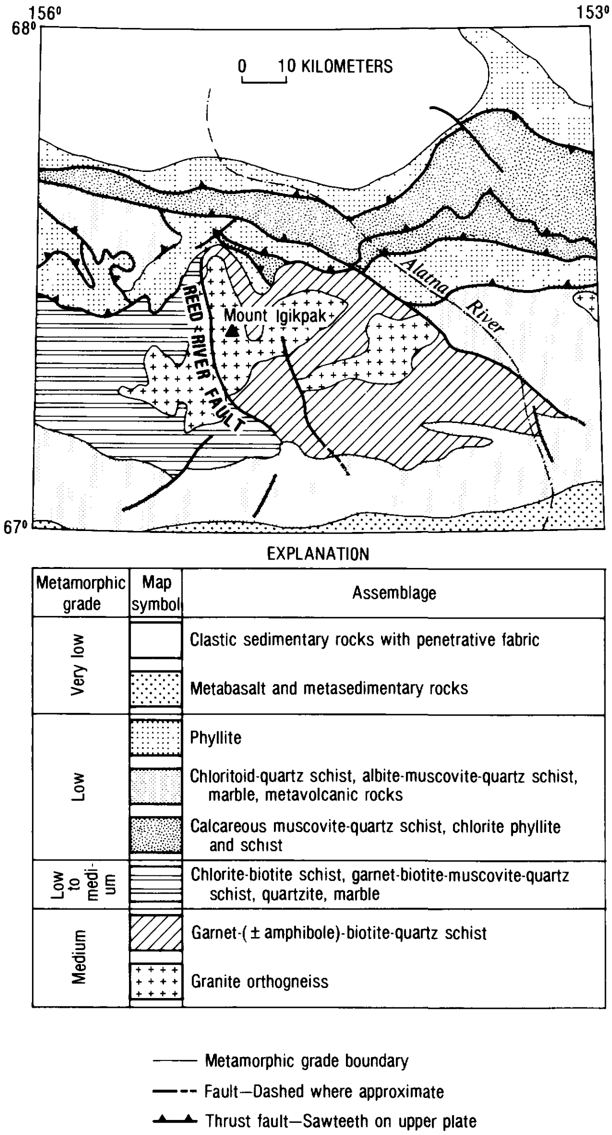

FIGURE 7.—Generalized metamorphic grade map, Survey Pass quadrangle.

has established a possible Precambrian metamorphic event, Middle Devonian igneous activity, and a Mesozoic (largely Cretaceous) regional metamorphic event (Turner and others, 1978; Dillon and others, 1979; Silberman and others, 1979).

The contacts between the metamorphic assemblages in the north-central part of the quadrangle are thrust faults (relative movement is upper plate northward). In the central and southern part of the quadrangle, high-angle, north-south trending faults offset the metamorphic grade contacts. The relations between the faulting and the grade or assemblages indicate that these faults are probably late syntectonic to posttectonic.

Mull and Tailleur (1977) suggested a late Mesozoic tectonic event that resulted in large-scale crustal shortening in the Brooks Range culminating in Neocomian time. This event resulted in the accumulation of thrust sheets in the central part of the Brooks Range. After the period of crustal shortening, tectonism changed to dominantly vertical, basement-involved tectonics (Mull, 1977).

Regional metamorphism probably began when the parautochthonous rocks of the southern Brooks Range were buried and deformed by thrust sheets that were successively imbricated and stacked above them. As tectonism waned in the Late Cretaceous, metamorphism came to an end, as indicated by potassium-argon cooling ages obtained from metamorphic micas along the southern flank of the Brooks Range (Turner and others, 1978).

Therefore, we suggest that the thrust faults bounding distinctive metamorphic assemblages northeast of the Alatna River are the result of Late Cretaceous vertical tectonics and that they developed just before the end of or after cessation of Cretaceous tectonism in the Brooks Range. The upper limit on the age of this thrust faulting, on the basis of radiometric dating, is approximately 110 m.y. The high-angle vertical faults are probably younger than the thrust faults. The higher grade of metamorphic rocks in the central part of the quadrangle is more likely to have been caused by deep burial during Mesozoic tectonism than by emplacement of the Middle Devonian orthogneiss.

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Rubidium-strontium and potassium-argon dating of emplacement and metamorphism of the Arrigetch Peaks and Mount Igikpak plutons, Survey Pass quadrangle, Alaska

By M. L. Silberman, D. G. Brookins,[3] S. W. Nelson, and Donald Grybeck

The Arrigetch Peaks and Mount Igikpak plutons on the central Survey Pass quadrangle, Alaska, are pervasively metamorphosed, deformed, and recrystallized (Nelson and Grybeck, 1978, 1979). The plutons, which are dominantly two-mica granites with high content of silica, alkalis, rubidium, uranium, and thorium, and low content of strontium, magnesium, and calcium, intrude sedimentary rocks of Devonian age and metasedimentary and metavolcanic rocks of Precambrian (?) and Paleozoic age of the schist belt of the southern Brooks Range. All gradations occur between typically granitic-textured rock and gneiss (Nelson and Grybeck, 1978). Previously, the granitic rocks were thought to have been emplaced synkinematically during a major Cretaceous metamorphic episode that affected the schist belt (Fritts and others, 1971; Brosgé and Pessel, 1977; Turner and others, 1978). This view is supported by potassium-argon ages of 86 to 92 m.y. from biotite and muscovite in three samples of the Arrigetch Peaks pluton (Brosgé and Reiser, 1971; Turner and others, 1978). Nelson and Grybeck (1978), however, citing petrographic and structural evidence that the plutons were cataclastically and protoclastically emplaced and were later subjected to further cataclastic deformation, recrystallization, and folding, suggested that they were considerably older than Cretaceous.

To determine the age of emplacement and timing of metamorphism, samples of the plutons have been collected for whole-rock rubidium-strontium dating, and samples of skarn and amphibolite zones in the dominantly greenschist-facies country rocks that surround them have been collected for potassium-argon dating. Three samples each from the Mount Igikpak and Arrigetch Peaks plutons fall on a $^{87}Sr/^{86}Sr$ $^{87}Rb/^{86}Sr$ isochron which gives a slope equivalent to an age of 373 ± 25 m.y. and an intercept (initial $^{87}Sr/^{86}Sr$ ratio) of 0.714 ± 0.003 (fig. 8). Potassium-argon ages from biotite and hornblende, separated from a skarn adjacent to the eastern contact between the Arrigetch Peaks pluton and calcareous Devonian sedimentary rocks, are 95 ± 3 and 109 ± 3 m.y., respectively.

The rubidium-strontium data indicate that the plutons were emplaced in Middle Devonian time. The isochron age agrees with a discordia uranium-lead zircon age of 360 ± 10 m.y. determined from zircons from several plutonic bodies and felsic volcanic rocks in the schist belt from the Ambler River, Survey Pass, and Wiseman quadrangles (Dillon and others, 1979). The apparently high initial $^{87}Sr/^{86}Sr$ ratio suggests that the Survey Pass granites may be mobilized older crustal material. Scatter about the isochron is higher than would be expected if the rocks had been completely closed to gain and loss of strontium and rubidium since crystallization. Multiple episodes of metamorphism resulting in slight changes in total rubidium and strontium may explain the scatter, but the granitic rocks more likely were mobilized and melted from crustal materials of somewhat variable initial strontium isotope ratio and may perhaps represent multiple intrusion of similar magma. To test this suggestion, additional whole-rock and mineral rubidium-strontium analyses are being made from samples collected over the entire 1,000-km^2 outcrop area of the granitic rocks.

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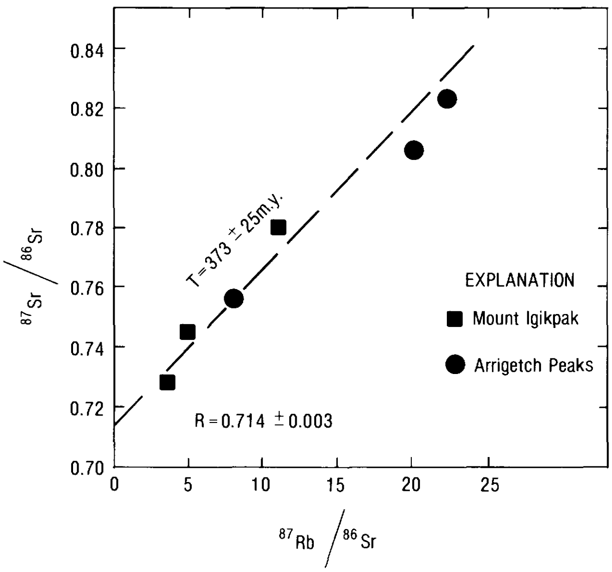

FIGURE 8.—Rubidium-strontium data, Arrigetch Peaks and Mount Igikpak plutons, Survey Pass quadrangle. T, age; R, initial $^{87}Sr/^{86}Sr$ ratio.

The biotite and hornblende ages are considerably younger than the rubidium-strontium whole-rock isochron age and are themselves internally discordant. Hornblende retains argon during post-crystallization thermal events better than do biotite and muscovite (Hanson and Gast, 1967). These potassium-argon ages, along with the three 86- to 92-m.y. biotite and muscovite potassium-argon ages from the Arrigetch Peaks pluton reported by Brosgé and Reiser (1971) and by Turner, Forbes, and Mayfield (1978), suggest that postemplacement metamorphism affected the plutons and their surrounding wallrocks between the Middle Devonian and middle Cretaceous, when the hornblende from the skarn cooled to temperatures at which argon could no longer be lost from diffusion. The younger mica ages suggest that temperatures in the region remained at high enough levels to permit argon loss from the biotite and muscovite for another 20 m.y. or so. Final cooling evidently occurred in the Late Cretaceous.

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Metallogeny of the Brooks Range, Alaska

By Donald Grybeck and Warren J. Nokleberg

Recent geochronologic studies and geologic work by government and industry substantiate a major late Paleozoic metallogenic epoch in the Brooks Range that includes all of the better known mineralization. However, the complex geology of the Brooks Range is known only from reconnaissance and limited exploration. Much work needs to be done on details of the mineralization.

Mineralization includes diverse types of deposits, as outlined below. For a synopsis of the mineral deposits and the literature through 1977, see Grybeck (1977).

1. A 150-km east-west belt of stratiform, volcanogenic copper-zinc deposits associated with rhyolite piles occurs in Devonian (possibly Precambrian) schist along the south side of the Brooks Range. This is the so-called "copper belt" which is being actively explored.

The Arctic deposit, the largest known, contains 30–35 million tons of rock with 4 percent copper, 5.5 percent zinc, and minor silver; numerous similar deposits are known (Sichermann and others, 1976); Smith and others, 1977, 1978; Marrs, 1978).

2. The Bornite deposit in the Cosmos Hills, located south of the "copper belt", has a similar association of copper, zinc, and minor silver, but its structure differs and its origin is less certain. The deposit consists mainly of high-grade, bornite-chalcopyrite-chalcocite-sphalerite breccia zones in Devonian carbonate rocks (Sichermann and others, 1976). The mineralization is syngenetic in part, but most is epigenetic. Recently identified tuffs in the carbonate section and unpublished lead isotope data suggest that the Bornite deposit may be contemporaneous with the Arctic deposit (A. K. Armstrong, oral commun., 1978).
3. Paleozoic granite with polymetallic mineralization is exposed in the Romanzof Mountains in the northeastern Brooks Range and in a discontinuous belt of plutons in the core of the range. Sable (1977) indicates a probable Devonian age for the Romanzof Mountains granite although the uranium/lead ages range from 310 to 450 m.y. Unpublished uranium/lead ages on the Arrigetch Peaks and Mount Igikpak granites in the central part of the range (John Dillon, oral commun., 1978) indicate a Devonian age of emplacement, as do rubidium-strontium analyses (Silberman and others, 1979). The Cretaceous potassium-argon data used to date these plutons in the past probably represent a thermal event and not initial emplacement. The peripheries of the granites are marked by numerous small occurrences of vein and contact metamorphic mineralization with various combinations of tin, molybdenum, tungsten, lead, zinc, silver, antimony, and uranium.
4. Stratiform zinc-lead (-barite) deposits occur at Drenchwater Creek, at the Red Dog and Lik prospects, and at several other localities in the northwestern Brooks Range. The mineralization consists mainly of fine-grained galena and sphalerite in black chert, shale, and the volcanic graywacke unit of the Lisburne Group, here of Mississippian age, and in siltstone, chert, and shale of the Siksikpuk Formation of Permian age (Nokleberg and Winkler, 1978; Plahuta, 1978; Nokleberg and others, 1979). The host rocks are dismembered by regional thrust faulting; the mineralization is syngenetic but shows evidence of remobilization of sulfides during or soon after deposition. The Drenchwater and Red Dog deposits are associated with Mississippian keratophyres, andesites, and volcanic graywackes. All the deposits are likely to be of marine hydrothermal origin.
5. In the Chandalar quadrangle, a northeast-trending mineral belt at least 60 km long coincides with a belt of granite to granodiorite plutons. The varied mineralization might best be considered a porphyry copper environment in the broad sense; that is, it includes porphyry copper and porphyry molybdenum deposits within the intrusive rocks, copper-bearing skarns adjacent to them, and further away, but probably still related to the plutons, lead-zinc-silver veins and replacement bodies. Paleozoic radiometric ages of 295 m.y., 380 m.y., and 495 m.y. of the plutons suggest their age of emplacement but are probably confused by later thermal events or experimental error. Several Cretaceous dates record a postemplacement thermal event. The long-known gold-quartz veins and placers east of the mineralized belt near Chandalar Lake may be distant manifestations of the plutonic belt, but their age can be substantiated only as Devonian or younger.
6. Gold placers near Wiseman and on the Squirrel River and its tributaries have produced intermittently since before World War I. A few placers can be traced back to thin, apparently inconsequential gold-quartz veins of Devonian or younger age; the great majority have no recognizable source.

The dominance of late Paleozoic mineralization in the Brooks Range (summarized on fig. 9), intrusion of Paleozoic plutons, probable Devonian metamorphism, and uplift reflected in the Upper Devonian clastic wedge of the central Brooks Range substantiate a late Paleozoic, if not Devonian, orogeny. A similar event, the Ellsmerian orogeny, is recognized in adjacent northwestern Canada; the Antler orogeny, perhaps a correlative event, is widespread in the western United States.

The geometry and timing of Paleozoic mineralization and orogeny are greatly complicated by late Mesozoic tectonism. Movements associated with it are not yet clear but probably reflect major plate motions. A current theory is that northern Alaska rotated about 75° counterclockwise from its former position adjacent to the Canadian Arctic Islands, mostly in Cretaceous time (Tailleur, 1973). The leading edge of the plate now generally coincides with the south side of the Brooks Range. A recent synthesis for the Yukon-Koyukuk Basin south of the Brooks Range (Patton, 1973) suggests that this Jurassic and Cretaceous basin, filled largely with Cretaceous graywacke, was largely oceanic until Jurassic time. Tailleur's hypothesis and plate tectonic theory provide numerous possibilities for subduction, obduction, telescoping of lithofacies, thrusting, and destruction of rocks at the leading edge of the rotating plate. Patton's hypothesis provides similar possibilities for movement in the oceanic rocks south of the Brooks Range at about the same time. These ideas can account for many aspects of the present geology of the Brooks Range, particularly the tens, if not hundreds, of kilometers of thrusting that are widely recognized and the uplift in what is now the core of the range, furnishing Cretaceous sediments to the Yukon-Koyukuk Basin to the south and to the Colville Basin to the north. These ideas are also controversial. Others have suggested that lateral faulting dominated late Mesozoic tectonism (for example, Yorath and Norris, 1975). Stabilistic syntheses which largely rely on vertical movements to account for the stratigraphic succession still play an important role in Brooks Range geology.

At this time no particular tectonic style can be conclusively shown as dominant; late Mesozoic tectonism in the Brooks Range will probably be shown ultimately to be some combination of rotational plate motion, lateral faulting, and vertical uplift. Although our understanding of the late Mesozoic tectonics of the Brooks Range is still in a formative stage, it is clear that the effects are so pervasive and far reaching that it is imperative that these movements be understood in order to reconstruct the original pattern of Paleozoic mineralization.

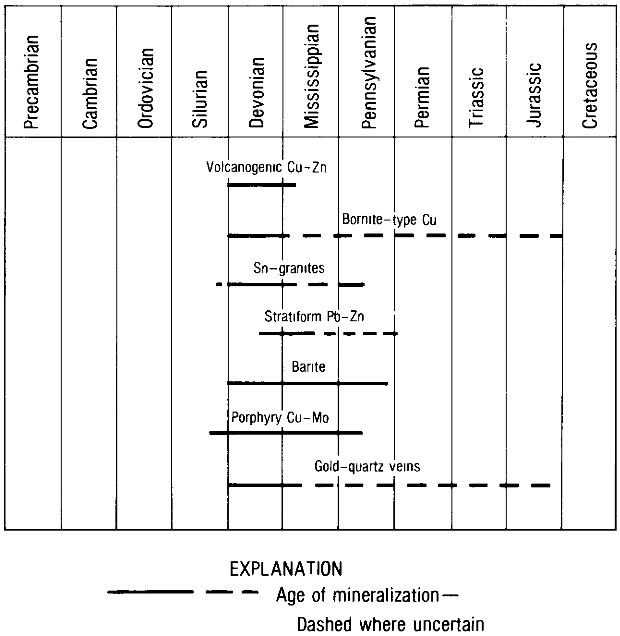

FIGURE 9.—Ages of major mineralization in Brooks Range.

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Tectonic model for the western Brooks Range, Alaska

By Michael Churkin, Jr., Warren J. Nokleberg, and Carl Huie

In the western Brooks Range, discrete stratigraphic sequences containing strata ranging in age from Devonian or Mississippian to Cretaceous are juxtaposed by major thrust faults (Tailleur and others, 1966; Tailleur and Snelson, 1968; Martin, 1970; Churkin and others, 1978; Mayfield and others, 1978; Roeder and Mull, 1978). Beneath the thrust plates, a structural sequence of upper Paleozoic to upper Mesozoic argillaceous and cherty rocks (Tailleur and others, 1966; Churkin and others, 1978; Mayfield and others, 1978), named the Kagvik sequence by Churkin and others (1979), provides a key to the tectonic history of arctic Alaska.

The Kagvik sequence lies structurally below thrust-faulted sheets of carbonate rocks and sandstone of the Lisburne Group, which in turn are overthrust by pillow lavas and layered mafic and ultramafic rocks. Along the south edge of the Brooks Range, the Kagvik sequence is overthrust by a terrane containing a mixture of quartz-mica schist, slate, and greenstone. Reconstruction of sedimentary environments indicates: (1) a shallow-water shelf environment for the thick, richly fossiliferous carbonate rocks of the Lisburne Group of Carboniferous age; and (2) a deep ocean-floor environment for the highly internally deformed Kagvik sequence, which is a relatively thin (about 500 m) section containing abundant radiolarians and *Nereites* trace-fossil assemblages and local andesitic tuff and flows. Limestone turbidites interbedded with the pelagic sediments of the Kagvik sequence suggest that a carbonate shelf was nearby and that a continental margin existed during the late Paleozoic and early Mesozoic near the present-day southern Brooks Range. In our tectonic model, we propose that telescoping of this longstanding continental margin may be related to collision of the margin with Paleozoic island arcs and Precambrian or Paleozoic microcontinental blocks now represented by the metamorphic terrane along the south flank of the Brooks Range. Other tectonic models for the western Brooks Range have been proposed by Martin (1970), Tailleur and Brosgé (1970), Tailleur (1973), and Roeder and Mull (1978).

Bedrock across the western Brooks Range can be divided into three terranes (fig. 10*D*). A central terrane is composed of the highly deformed Kagvik sequence and overlying thrust plates of coeval shelf carbonate rocks and dismembered mafic and ultramafic assemblages. A northern terrane is composed of younger, mainly upper Mesozoic, rocks that underlie most of the North Slope. A southern terrane in the southern Brooks Range and along the north edge of the Yukon-Koyukuk Basin is composed of schist, marble, metarhyolite, volcanogenic sulfide de-

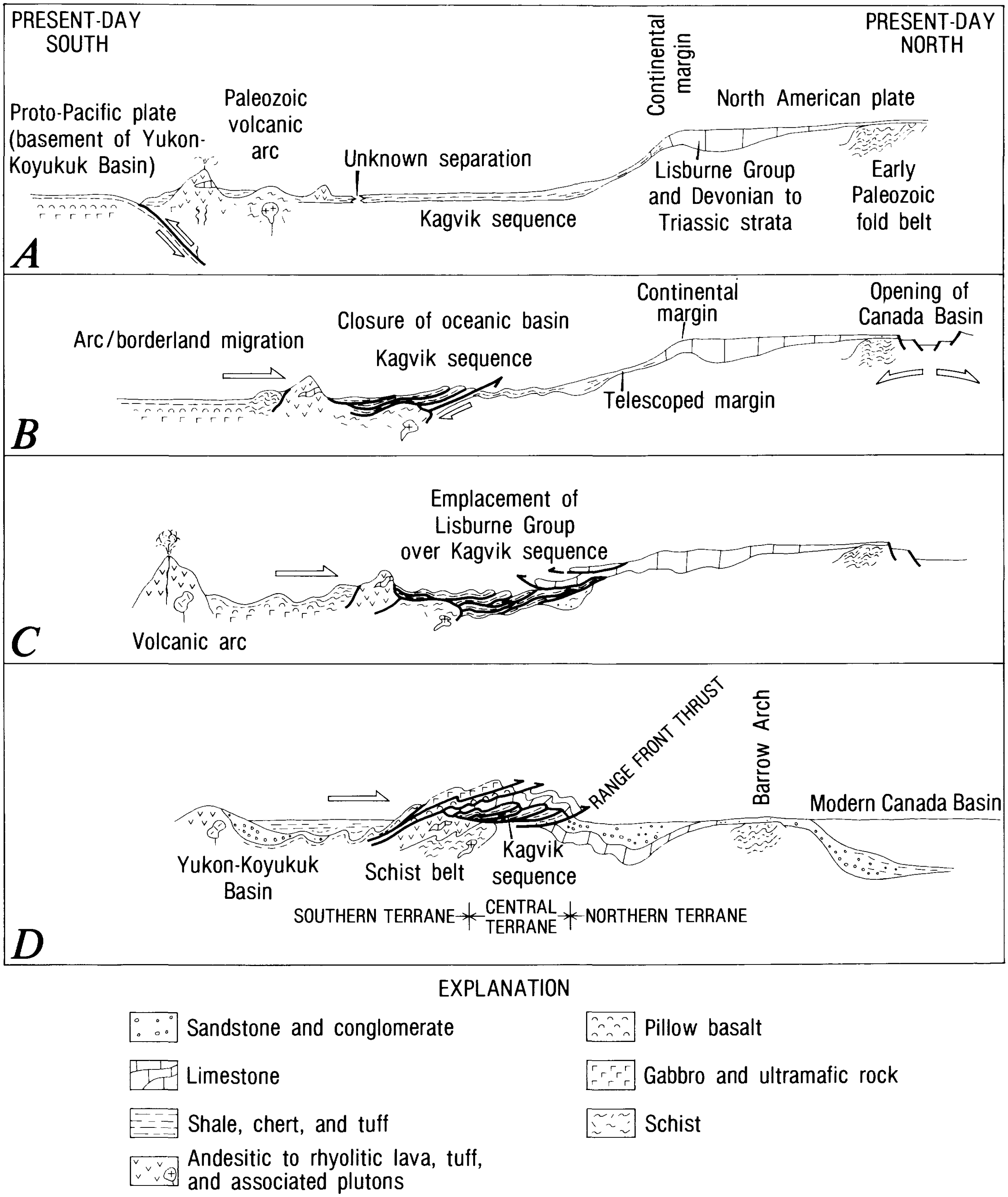

FIGURE 10.—Postulated deformation of Paleozoic and Mesozoic continental margin, arctic Alaska. Ages of structural events approximate. *A*, Carboniferous to Triassic. *B*, Late Jurassic or Early Cretaceous. *C*, Cretaceous. *D*, Late Cretaceous.

posits, blueschist, and dismembered ophiolite and other metamorphic rocks of probable Precambrian to Devonian and Mississippian ages (Forbes and others, 1977; Smith and others, 1978; Patton and others, 1977). This southern terrane is probably a composite of several oceanic terranes, including volcanic arcs and ocean-floor sediments, separated by major sutures. The large areas of quartz-rich mica schist associated with a composite batholith of predominantly gneissic granite and lesser quartz monzonite in the northern part of the southern terrane (Brosgé and Pessel, 1977; Mayfield and Tailleur, 1978) seem to be the root zones of a remnant magmatic arc.

The rocks of the western Brooks Range formed roughly as follows: (1) In the Carboniferous, carbonate rocks and sandstone of the Lisburne Group were deposited in a broad continental shelf environment (Armstrong, 1974). Meanwhile, siliceous pelagic sediments and andesitic flows and tuffs formed in an oceanic environment off the south edge of the North American continental margin somewhere near the southern margin of the present-day Brooks Range (fig. 10*A*). (2) Sometime during the Late Jurassic or Early Cretaceous, these rocks were intensely deformed, isoclinally folded, and imbricately thrust faulted (fig. 10*B*), thereby forming the Kagvik sequence. This deformation probably was the product of a collision of a microcontinental block or volcanic arc, now represented by some part of the southern Brooks Range terrane, with pelagic sediment of the Kagvik sequence. The gently north-dipping thrust contact of the Kagvik sequence with quartz-mica schist and greenstone of the southern Brooks Range terrane can be interpreted as a suture of the two terranes. (3) With continued Cretaceous deformation, the rocks of the continental margin were themselves deformed and carbonate shelf sequences were thrust over the Kagvik sequence. This telescoping of the long-standing continental margin is probably related to collision of microplates from the Pacific, and perhaps also to the counterclockwise rotation of arctic Alaska in the Late Jurassic or Early Cretaceous, possibly during rifting and opening of the modern Canada Basin (fig. 10*B*). (4) By the end of the Cretaceous further deformation caused thrusting and infolding of carbonate rocks with the Kagvik sequence. The south edge of the foredeep along the north front of the Brooks Range was also deformed (fig. 10*C*). Toward the end of this deformation (fig. 10*D*), thrust slices of mafic and ultramafic rocks, representing in part a dismembered ophiolite basement of the Yukon-Koyukuk Basin, were emplaced on top of the allochthonous sheets of the Lisburne Group (Patton and others, 1978). The tectonic events that produced this last major deformation may be related to movements of the southern Brooks Range terrane, either as a collage of accreted microplates or as individual microcontinental blocks or volcanic arcs that were accreted against the telescoped continental margin of North America.

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Upper Paleozoic volcanic rocks in the eastern and central Brooks Range

By H. N. Reiser, W. P. Brosgé, J. T. Dutro, Jr., and R. L. Detterman

For a long time upper Paleozoic volcanic rocks were thought to be absent from northeastern Alaska. However, field and laboratory studies in 1978 confirmed, extended, and more exactly dated recently recognized upper Paleozoic volcanic rocks in eastern and central Brooks Range.

In 1972 a small allochthonous block of rocks southeast of Porcupine Lake (fig. 11, loc. 1) was found to be predominantly composed of volcanogenic rocks. Lenses of volcanic conglomerate, volcanic wacke, volcanic breccia, tuff, and tuffaceous limestone occur with dioritic or basaltic andesite flows. The sequence is about 60 m thick and generally the rocks are pale green, weathering to orange. Original minerals are to a large extent chloritized and altered: clinopyroxene has been replaced by chlorite and plagioclase by clay; pyrite is common. Locally the volcanic wacke in contact with the limestone is fine grained, and it contains chips of silicified limestone or siltstone.

The age of the tuffaceous limestone interbedded with the volcanic rocks was determined initially to be late Paleozoic (Permian) on the basis of foraminifers and coral fragments (A. K. Armstrong, written commun., 1972). A more precise age determination of diagnostic brachiopods by Dutro shows that the tuffaceous limestone is equivalent in age to the Ikiakpaurak Member of the Echooka Formation of the Sadlerochit Group (Late Permian).

More significant, because the rock sequences are autochthonous, was the subsequent recognition of similar volcanogenic rocks north of Porcupine Lake. About 5.5 km north of Porcupine Lake (fig. 11, loc. 2) local mineralization in sedimentary rocks appears to involve similar but somewhat older volcanogenic rocks (Barker, 1978). The reported stratigraphic relations of these volcanogenic rocks (J. L. Peace, written and oral commun., 1978) suggest that they grade laterally into and in part overlie Mississippian or Pennsylvanian limestone of the Lisburne Group.

The volcanogenic sequence on the Ivishak River 58 km to the northwest (fig. 11, loc. 3; U.S. Geological Survey, 1977) was probably laid down during the same period of volcanic activity. This sequence crops out over a 10-km-long area extending north and south of the river. A dark-colored band of rocks within the Lisburne Group about 5 km to the east and extending northward may be an extension of these volcanogenic rocks. The Ivishak River volcanic sequence includes breccia, tuff, volcanic conglomerate, tuffaceous limestone, flows that are locally pillowed, and minor interbedded limestone. The estimated thickness of the sequence ranges from 115 m on the north side of the Ivishak River to about 200 m on the south side. Locally, heavy iron-sulfide mineralization is apparent in both the volcanic rocks and the adjacent limestone. The age of the volcanogenic sequence is probably Late Mississippian on the basis of the identification of a Zone 18 or younger microfaunal assemblage (K. J. Bird, oral commun., 1978) in limestone immediately underlying the volcanic sequence and Dutro's field identification of Mississippian brachiopods, bryozoans, and echinoderms in the tuffaceous limestone. The volcanic sequence examined on the Ivishak River is entirely extrusive and may be the vented phase of the volcanism that em-

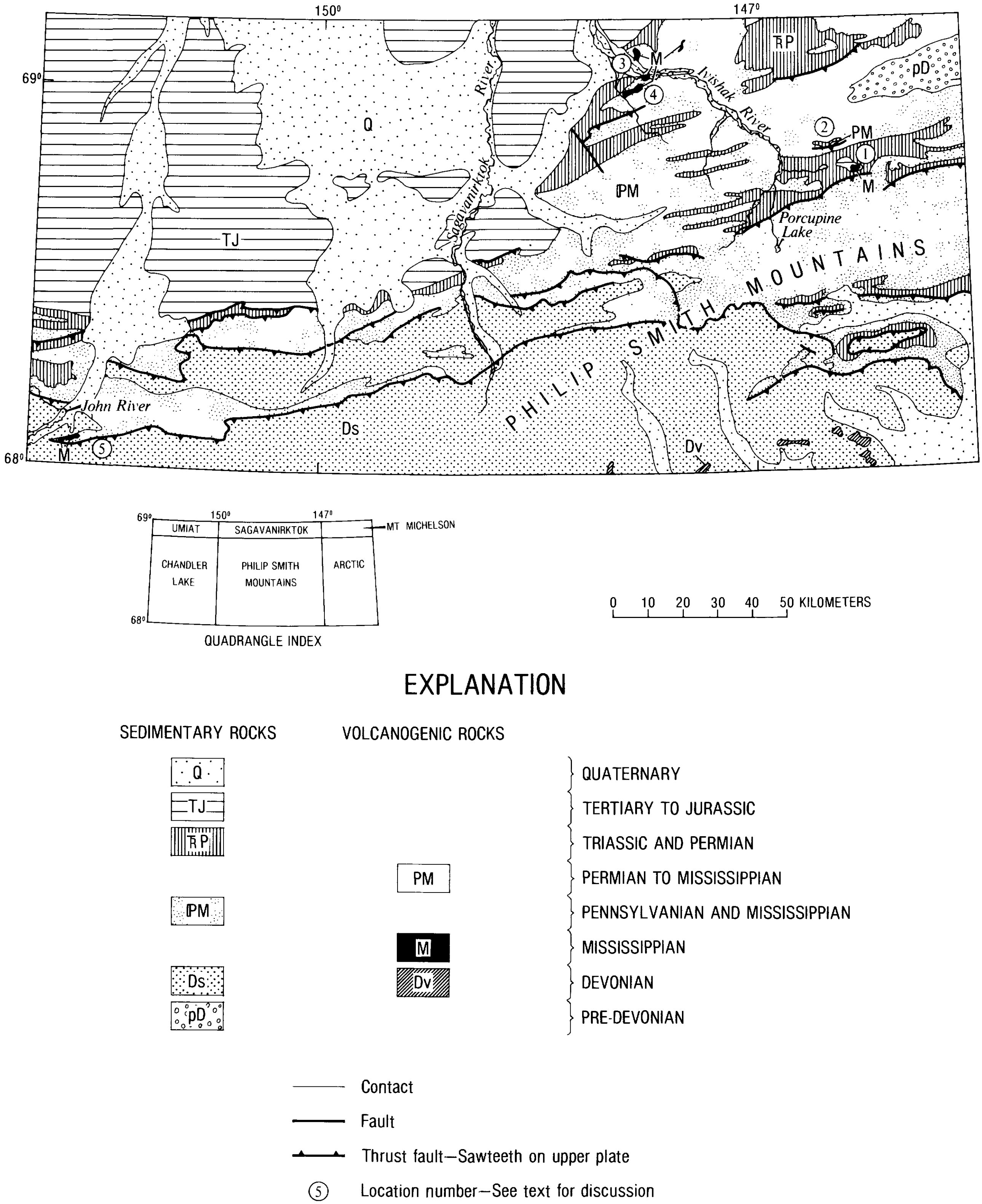

FIGURE 11.—Generalized geologic map, eastern and central Brooks Range. (Geology by Reiser and others, this report; Keller and others, 1961.)

placed the andesite-diabase sill in limestone of the Lisburne Group 1.5 km to the southwest (fig. 11, loc. 4) (Keller and others, 1961).

The other known occurrence of upper Paleozoic volcanogenic rocks in this region is marked by several outcrops in an area approximately 14 km south of Anaktuvuk Pass on the headwaters of the John River (fig. 11, loc. 5). The volcanogenic rocks are tightly folded and faulted along with the enclosing shale and limestone. The exposed sequence is probably not more than 30 m thick, ranges from tuff to pebble and boulder conglomerate, and locally includes tuffaceous limestone. Although no flow rock was found in place, several pieces of vesicular, highly chloritized basaltic(?) andesite were seen in the scree. The tuffs are massive to schistose, and most of the original minerals are thoroughly chloritized and altered to clay so that only rare relict fragmentary plagioclase and clinopyroxene are preserved. On the basis of available evidence, the volcanic rocks were originally andesite to basaltic andesite. Although lithologically similar to the volcanogenic sequences previously described, the sequence at Anaktuvuk Pass is older. It occurs in the Lower Mississippian Kayak Shale, encloses small boudins of fossiliferous Lower Mississippian limestone, and locally contains blastoids in calcareous tuff. The occurrence of the productids *Orbinaria* and *Pustula* together with other macrofossils strongly indicates an Early Mississippian, probably late Kinderhookian, age.

Thus it is now known that volcanogenic rocks of Early Mississippian, Late Mississippian, and Late Permian age are present in central and eastern Brooks Range.

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Late Cenozoic glaciations and erosion intervals, north-central Brooks Range

By Thomas D. Hamilton

Drift sheets and erosion surfaces in the Anaktuvuk River region document four successive drift complexes of late Tertiary and Pleistocene glaciation that followed and were separated by long-lasting intervals of widespread river planation (table 1). The oldest surface, 135–165 m above modern flood plains, truncates bedrock and bears a gravel cap as thick as 10 m. Although large erratic boulders are absent, abundant large cobbles and very small boulders indicate high transport energy and are similar in shape and composition to stones in Pleistocene outwash derived from the Brooks Range.

The oldest drift and landforms possibly created by glacial abrasion occur near Gunsight Mountain in areas clearly beyond the limits of the Anaktuvuk River Glaciation mapped by Detterman, Bickel, and Gryc (1963). These deposits, here informally termed Gunsight Mountain drift, may represent either one or several individual glaciations. Erratic boulders of probably correlative age are scattered across erosion surfaces 75–100 m high south and southwest of Gunsight Mountain. Exposures typically exhibit truncated bedrock capped with alluvium that contains residual erratics and is overlain in turn by loess. Distribution of the Gunsight Mountain drift and of the erosion surfaces that formed before and after glaciation reflect drainage patterns appreciably different from those of the present. Chandler River flowed northeast as a tributary to the Anaktuvuk River at that time, and Nanushuk River flowed northeast as a tributary to the Itkillik.

The symmetrical placement of drift of the Anaktuvuk River Glaciation within modern river valleys indicates that major drainage patterns had evolved to essentially their present configuration by the time of this glacial advance. Along Anaktuvuk valley, Anaktuvuk River drift has been eroded to a width of 5.5 km by streams flowing at a level about 60 m above the modern flood plain. Comparable erosion surfaces, 45–65 m above modern stream levels, dissect Anaktuvuk River drift in valleys farther to the east and west.

Drift of the Sagavanirktok River Glaciation lies nested within Anaktuvuk River moraines. It

TABLE 1.—*Late Cenozoic glacial succession, Anaktuvuk River region*

	Porter (1964)	This paper
Neoglaciation	Fan Mountain Glaciation	Fan Mountain Glaciation
	Alapah Mountain Glaciation	-------------
Itkillik Glaciation	Anivik Lake Stade	-------------
	----------------	Late Itkillik readvance
	Antler Valley Stade	Itkillik II
	Anayaknaurak Stade	-------------
	Banded Mountain Stade	Itkillik I
	------------------	Early Itkillik(?)

extends to within 35–45 m of modern floodplain levels in Anaktuvuk valley, where it appears to form two distinct sheets that subsequently have been eroded to widths of about 4.5 and 3.0 km. As at its type locality along the Sagavanirktok River, 100 km east of Anaktuvuk valley (Hamilton, 1978), the Sagavanirktok River drift forms two surfaces that contrast in postglacial modification and possibly were separated by an interglacial rather than interstadial interval. In smaller valleys farther to the west and east, Sagavanirktok River drift appears to form only a single body and is associated with outwash trains that stand 20–25 m above modern stream levels.

Deposits of the Itkillik Glaciation, of late Quaternary age, occupy modern valley floors and are less modified than Sagavanirktok River drift. Itkillik drift sheets are divisible into two principal subunits, Itkillik I and Itkillik II, throughout the central Brooks Range (Hamilton and Porter, 1975). Itkillik I end moraines are relatively subdued in appearance and are dissected by axial streams, which commonly have cut about 15 m into underlying bedrock. The moraines almost entirely overlapped a somewhat older drift of presumed early Itkillik age that still was ice cored at the time of the Itkillik I glacial advance. The less extensive Itkillik II moraines are morphologically fresh and appear to be still ice cored in parts of the Anaktuvuk and Nigu valleys and near Natvakruak Lake. This advance was followed by a readvance into lake deposits that formed behind Itkillik II moraines, and then by a long interval of ice downwastage and stagnation within major valleys of the Brooks Range.

Detailed studies of type localities within the Anaktuvuk valley indicate that substantial revisions are necessary in the late Quaternary glacial sequence developed by Detterman, Bowsher, and Dutro (1958) and later modified by Porter (1964). The Itkillik Glaciation appears to consist of three or four separate advances, only two of which coincide with Itkillik events defined by Porter (tables 1, 2). Porter's Anayaknaurak Stade is deleted because the type locality for its drift exhibits diamicton of probable colluvial rather than glacial origin. This deposit formed along an eroding cut bank that intersected till of Itkillik I age and caused it to flow downslope under gravity. Type deposits for Porter's Anivik Lake Stade are now considered to be part of an extensive complex of subglacial meltwater deposits that formed during widespread stagnation and downwasting of late Itkillik ice. They do not represent a distinct glacial readvance. Moraines that comprise the deposits at the type locality of the Alapah Mountain Glaciation of Detterman and his co-workers are impressive lateral moraines of late Itkillik age that terminate at the former interface between stagnating glacier ice in the upper Anaktuvuk Valley and still-active tributary ice streams originating in high-altitude cirques near the Continental Divide.

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Record of a prehistoric storm surge in the Wainwright Inlet-Kuk River area

By D. M. Hopkins, R. W. Hartz, and S. W. Robinson

Storm surges along the Beaufort and northern Chukchi Sea coasts have occasionally reached heights of 3 m above mean sea level during the present century (Aagard, 1978; Reimnitz and Maurer, 1978). The frequency of these events is not yet known, nor has there been evidence that

TABLE 2.—*Late Quaternary glacial succession, Anaktuvuk valley*

Age	Glaciation	
Holocene	Fan Mountain Glaciation	
Late Pleistocene	Late Itkillik Itkillik II Itkillik I Early Itkillik(?)	Itkillik Glaciation
35-45 m surface		
Middle Pleistocene	Sagavanirktok River II Sagavanirktok River I	Sagavanirktok River Glaciation
45-65 m surface		
Early Pleistocene	Anaktuvuk River Glaciation	
75-100 m surface		
Late Tertiary(?)	Gunsight Mountain drift	
135-165 m surface		

surges of this height took place in earlier times. Evidence from the Wainwright Inlet-Kuk River area suggests, however, that storm surges of similar intensity took place in the prehistoric period. During fieldwork in 1976, we observed features along the Kaolak River which seem to record a storm surge that raised sea level about 3 m above the present level of the confluence of the Kuk and Kaolak Rivers during a late summer storm more than 1,000 years ago.

Kuk River is a tidal estuary connected to the Chukchi Sea by way of Wainwright Inlet, forming an estuary and tidal river system that extends some 60 km southward and inland from the Chukchi Sea coast (fig. 12). The lower 38 km of the system is brackish and lies at sea level. A confined delta 4.5 km long separates the estuarine lower Kuk River from the 18-km-long upper Kuk River, which is fresh and flowing but has current speeds and channel form strongly influenced by tides in the estuary. The tidal influence seems to end at the point where the Kaolak and Avalik Rivers join to form the Kuk River.

The Kaolak River, in its lower 5 km, flows in a narrow valley incised into the Cretaceous bedrock of the highest, innermost, and oldest of the three marine terraces comprising the Arctic Coastal Plain of Alaska (Williams and others, 1977). The meandering channel is confined between banks consisting alternately of bedrock and the alluvium of a series of alluvial terraces which stood 3.5 to 4.5, 7, and 14 m above river level on July 22, 1976, when stream discharge was low after about 10 days of dry weather.

The lowest of these terraces slopes more steeply than present-day river grade, standing 3.5 m above river level near the confluence with the Avalik River and 4.5 m above river level at a point 5 km upstream. Field observations indicate that the terrace must be relatively young. Oxbow lakes and marshes unmodified by thermokarst processes can be observed on the terrace surface, and vertical exposures show that ice wedges are sparse and small. These observations suggest that the 3.5- to 4.5-m terrace is of Holocene age.

The 3.5- to 4.5-m terrace consists in most places of horizontal beds of sandy alluvium 2 to 10 cm thick; concentrations of willow and other plant leaves and driftwood twigs delineate the bedding planes. The only vertebrate remains

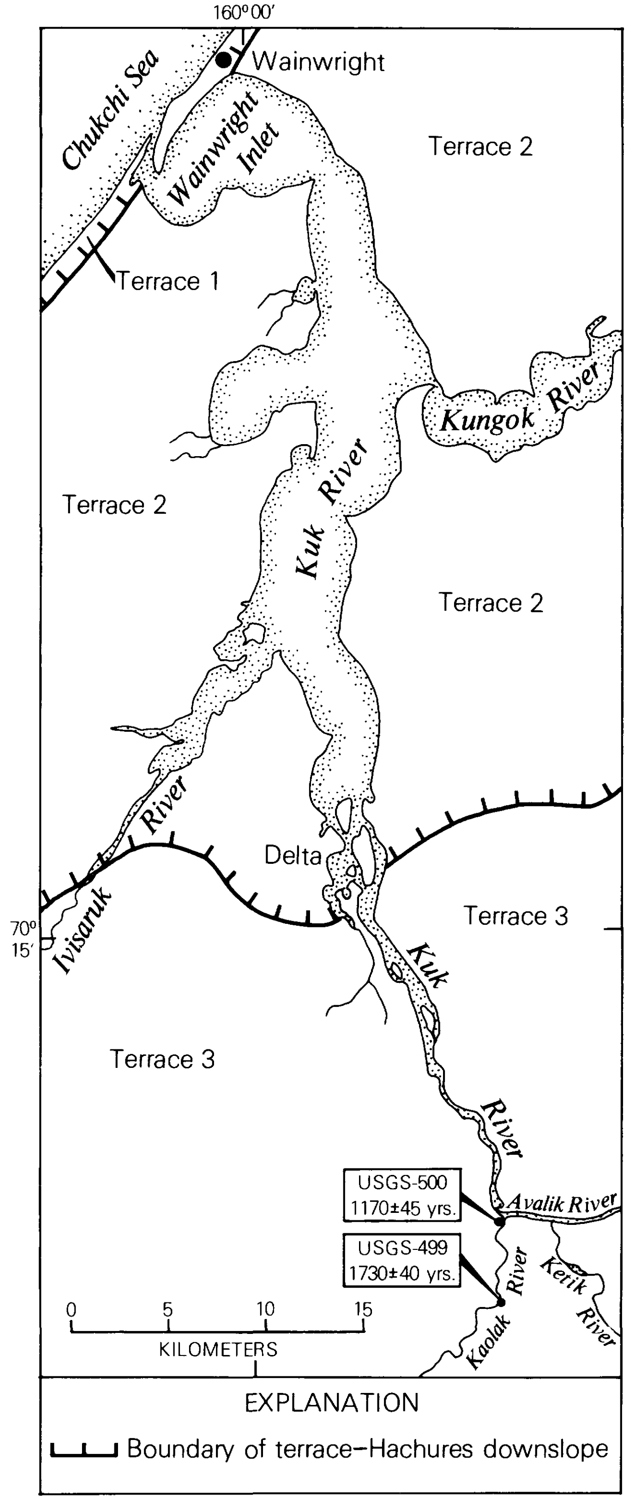

FIGURE 12.—Position of Kaolak River in Kuk River drainage basin.

found consist of a fragment of reindeer antler. However, along the west bank of the Kaolak

River at a point 250 m upstream from its confluence with the Avalik River, the flat-bedded alluvium of the 3.5- to 4.5-m terrace passes downstream into foreset-bedded medium sand with interbeds of twigs and leaves. The inclined beds extend from river level to a height of 3.0 m and are overlain by 0.5 m of flat-bedded peaty find sand.

Radiocarbon analyses show that the 3.5- to 4.5-m terrace of the lower Koalak River formed during a brief period of alluviation approximately 1,000 to 2,000 years ago. Twigs collected 3.7 to 3.8 m below the surface of the 4.5-m terrace, 5 km upstream from the river mouth, yielded a radiocarbon age of 1,730 ± 40 years (USGS-499), and twigs collected from the foreset-bedded sand at the river mouth yielded a radiocarbon age of 1,170 ± 45 years (USGS-500). Although the two samples consist of wood of different ages, the older sample may consist of wood redeposited from slightly older floodplain sediments and may have been deposited almost simultaneously with the younger sample. No unconformities, paleosols, or *in situ* peat were noted in a measured section at the upstream locality, and there is at least a possibility that the entire 4.5 m of sediment exposed above river level was deposited during a single flood episode, simultaneously with the foreset-bedded sediments at the river mouth.

The 3.5- to 4.5-m terrace of the lower Kuk River probably was formed during a brief period of high river discharge that coincided with a Chukchi Sea storm surge. The foreset bedding in the terrace deposits at the Koalak River mouth reflects abrupt decrease in current discharge and seems to indicate that at the time of deposition the upper Kuk River was ponded at a level 3 m above its level of July 22, 1976. The inclined surface of the Kaolak River terrace must reflect a temporarily steepened river gradient, probably resulting from the inability of the constricted lower Koalak River valley to accommodate a greatly increased floodwater flow. Although storm surges can occur in the Beaufort and Chukchi Seas at any season, they are most frequent and most severe during September and October (Aagard, 1978; Reimnitz and Maurer, 1978). The rivers of arctic Alaska experience their highest discharge and peak sediment load during spring snowmelt (Arnborg and others, 1967) but experience occasional floods during late summer and autumn storms as well. Karl Stefansson reports recent flood levels along the Kaolak and Ketik Rivers as high as 6 m during spring break-up in June 1948 (field notes in files of Technical Data Unit, Branch of Alaska Geology, U.S. Geological Survey, Menlo Park, Calif). The abundance of willow leaves in peaty interbeds suggests that the 3.5- to 4.5-m terrace of the Kaolak River was deposited during late summer or autumn, rather than during spring.

Study of the terrace deposits along the Kaolak River confirms that flood levels along the Kaolak River may even now occasionally reach levels more than 4.5 m above normal stream grade and that these floods may coincide with intense storm surges.

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Stratigraphy of the Gubik Formation at Skull Cliff, northern Alaska

By John R. Williams

Cliffs along the Chukchi Sea coast from Peard Bay 80 km northeastward to Barrow provide excellent exposures of the marine facies of the Gubik Formation of Quaternary age, of the underlying sandstone, shale, and clay of Cretaceous age (to within about 35 km of Barrow), and of the overlying thaw-lake basin deposits. The best exposures are at Skull Cliff (fig. 13), where a twofold subdivision of the Gubik has been noted by Leffingwell (1919, p. 149–150), Meek (1923), and Black (1964); in recent years the bluffs have been examined by the U.S. Geological Survey as part of investigations of the outer continental shelf by D. M. Hopkins, R. E. Nelson, R. W. Hartz, and P. A. Smith and by the

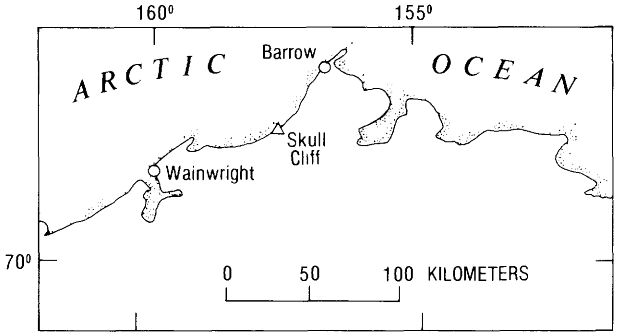

FIGURE 13.—Location of Gubik Formation at Skull Cliff, Meade River quadrangle.

writer as part of land-use studies of National Petroleum Reserve in Alaska (Chapter 105–C, P.L. 94–258) (Williams and others, 1977; Williams and others, 1978).

Black (1964, p. 65–68) reviewed the older observations and subdivided the Gubik Formation into the Barrow unit (grading laterally inland into the Meade River unit) and the underlying Skull Cliff unit, named for exposures near Skull Cliff about 48 km southwest of Barrow. The Skull Cliff unit at the type locality is "a 1–15 ft. thick bed of dark-gray sticky silty clay containing pebbles of granite and chert as much as 4 inches in diameter.***The top of the unit is fairly level.***it fills the uneven top of the (underlying) sandstone.***is blocky in some places and fissile in others, and becomes more silty and sandy upward. It is very poorly sorted and in part resembles a marine-deposited till." (Black, 1964, p. 67–68).

The overlying Barrow unit at Skull Cliff is described by Black (1964, p. 78) as follows: "Overlying the silty clay (Skull Cliff unit) in places apparently conformably and in others disconformably is 4 to 15 feet of tan, brown, and yellow very fine to fine-grained marine sand. Clean frosted grains are common in places and appear eolian. Elsewhere clay and silt are abundant and contain pebbles and numerous marine megafossils and microfossils.***the silt content of the upper sand is greater toward the base but is highly variable laterally and vertically." The writer was unable to locate Black's section but measured the section exposed in the second gully northeast of the mouth of Tuapaktushak Creek and 550 m southwest of triangulation station SKULL (lat 70° 54.71′ N., long 157° 37.10′ W.) as follows:

Description and interpretation	Meters above sea level
Slumped sand and silt with peat chunks; thaw lake deposits	19.2–22 (top)
Disconformity	
Brown and light-brown fine to medium sand and fine gravel in thin beds and lenses; no shells noted	15.0–19.2
Dark-gray silt, sand partings; marine shells	13.7–15.0
Thin-bedded fine sand, brown and black, detrital coal beds, pebbles of chert	12.5–13.7
Gray silty sand, minor sand lenses; scattered marine shells	10.75–12.5
Disconformity	
Thin shell hash mixed with lenses of sandy gravel; similar to beach deposits—horizontal	10.7–10.75
Unconformity	
Nearly vertical folded beds of dark-brown and gray fine sand and silty beds; numerous marine shells; amplitude of folds is several meters	6.4–10.7
Unconformity	
Clay with sand partings and irregular sand lenses; scattered marine shells and erratic stones—horizontal	5.5–6.4
Clayey silt, marine shells in sandier unit near top; indistinct basal contact. Basal part of Gubik Formation	4.75–5.5
Unconformity	
Weathered sandstone, clay and coal. Cretaceous	4.0–4.75
Shale, soft weathered sandstone, perhaps bentonitic beds. Cretaceous	2.5–4.0
Fine gray sandstone. Cretaceous	0–2.5 Sea level

Interpretation of this section suggests that Black's Skull Cliff unit is contained within the interval 4.75 to 6.4 m above sea level and that the overlying folded and horizontal sandy and silty, locally shell-bearing units from 6.4 to 10.7 m and from 10.75 to 19.2 m and the intervening shell-rich transgressive gravel from 10.7 to 10.75 m above sea level are equivalent to the Barrow unit as described in the Skull Cliff area by Black. Thus the section has an equivalent to the basal Skull Cliff unit and three subunits within the Barrow unit of Black, and the cap of thaw lake sediments.

Examination of some sea cliffs and creek banks as far as 25 km southwest and coastal bluffs as far as 15 km northeast (beyond which the sea cliffs are cut in lower marine terraces than that at Skull Cliff) failed to locate a section comparable in detail to that presented above. Nevertheless, observations were made at many places of horizontal tan to brown fine sand separated by a transgressive beachlike gravel from a lower, generally less spectacularly contorted to horizontal or massive dark-gray to dark-brown silty sand. The section at Skull Cliff must be representative of the Gubik Formation over a large area.

Megafossil collections from scattered localities in the Skull Cliff area were examined by Louie Marincovich of the U.S. Geological Survey. Most of the fossils were species now inhabiting the coastal waters, but *Neptunea (Neptunea) lyrata leffingwelli* (Dall), now extinct, and *Natica (Tectonatica) janthostoma* Deshayes, not now found in local coastal waters, are two of the forms that appear to be in the deformed marine sand, but not in the upper marine sand. A full discussion of the paleontology of the Gubik Formation is best deferred until completion of stratigraphic studies and systematic paleontological collections planned for the summer of 1979.

In summary, the Gubik Formation at Skull Cliff has five subdivisions, rather than two. They are a basal horizontal fine-grained sediment that lies unconformably on Cretaceous bedrock, a folded marine silty sand unit that appears unconformable on the basal unit, a horizontal transgressive gravel unconformable on the folded marine unit, a horizontal sand and silt disconformable on the transgressive gravel, and an upper disconformable thaw-lake basin deposit. Mechanisms for folding the lower marine silty sand without disturbing the underlying sediments might include collapse of sediment around a large ice block, or sliding along the underlying clayey sediment. The folds have too large an amplitude to be caused by ice wedge formation.

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Arctic Coastal Plain pingos in National Petroleum Reserve in Alaska

By L. David Carter and John P. Galloway

Seven hundred thirty-two pingos and pingolike features have been identified on the Arctic Coastal Plain within National Petroleum Reserve in Alaska (Galloway and Carter, 1978). The pingos were mapped as part of an investigation of surficial deposits (Williams and others, 1977; Williams and others, 1978) done in support of Chapters 105b (Environmental Impact Assessment) and 105c (Land Use Study) of the National Petroleum Production Act of 1976 (PL 94–258). Pingos in the Canadian arctic have been studied extensively (Mackay, 1973; Pissart and French, 1976), but the work cited above resulted in the first published map of pingo distribution of any part of the Alaskan Arctic Coastal Plain. Information reported below shows that the distribution of pingos in the mapped area is controlled by the character and thickness of unconsolidated deposits and by the occurrence of thaw lake basins.

A pingo is an ice-cored, dome-shaped hillock that occurs in permafrost (Porsild, 1938). Two types of pingos have been described—open system and closed system (Müller, 1963). Closed-system pingos occur in areas of continuous permafrost such as the Arctic Coastal Plain (Black, 1954) and grow as a result of expansion due to freezing of confined water in saturated sediments that are localized in and beneath drained, partially drained, or partially sediment-filled lake basins (Mackay, 1973). All pingos in the mapped area are closed-system pingos.

Although thaw lake basins are widespread on the coastal plain, pingos were identified only east of the Usuktuk River (fig. 14). The pingos were located on aerial photographs (scale about 1:50,000), and a few were visited and measured to check the reliability of the aerial photograph interpretation. The highest pingo measured is 21 m, but most are from 6 to 10 m high. A few low, broad, ice-cored mounds are as wide as 200 m and as long as 600 m. Ice-cored mounds less than about 3 m in height are not shown on the map because they cannot be detected with certainty at the scale of the aerial photographs.

More than 97 percent of the mapped pingos are in areas underlain by sand or sandy alluvium (fig. 14). The remainder occur within the area mapped as upland silt. Furthermore, all pingos within the upland silt unit are located along its northern border and within thaw lake basins that lie at or below the contact between upland silt and an underlying sand unit that is at least 15 m thick. Pingos were not observed in parts of the upland silt unit where bedrock, rather than sand, underlies the silt. The pingos, therefore, are limited to areas underlain by sandy unconsolidated deposits.

Additionally, within the areas mapped as sand or sandy alluvium, all but two of the pingos occur where the sand is thicker than 15 m. The western boundary of the pingo area is nearly the same as that between thick sand having no exposed bedrock along the Usuktuk River and thin sand that covers exposed bedrock along the Meade River and streams draining west to the Chukchi Sea (fig. 14). North of the area of numerous pingos, thin sand overlies fine-grained Pleistocene deposits and bedrock. Pingos in sandy alluvium occur where bedrock is not exposed, and thus the alluvium may be relatively thick. It appears, therefore, that in the area mapped, thick sandy deposits are most favorable for pingo growth. Pingos of the Mackenzie River delta area in Canada also are underlain by thick sand, which occurs from 3 to 6 m below the surface and extends to an undetermined depth (Mackay, 1962).

The occurrence of pingos in sandy deposits but not in silty deposits within the study area is perhaps explainable in terms of the mechanism of pingo growth and by observations of the influence of sediment texture or pore water during freezing. According to Mackay (1973), an essential factor in pingo growth is the expulsion of water at the freezing front of aggrading permafrost into the closed system beneath the lake basin. The expulsion of water provides the hydrostatic pressure and continuing water supply necessary for pingo growth. In at least some cases, a lens of free water is present at the base of growing pingos (Mackay, 1977). Laboratory studies have demonstrated that under most conditions sand can expel water during freezing, whereas fine-grained silt may attract water to the freezing front (McRoberts and Morgenstern, 1975). If water is not expelled from the freezing front, ice segregations will occur within the aggrading permafrost and pingos will not grow.

The occurrence of pingos primarily in thick sandy deposits may indicate that a minimum thickness of saturated unfrozen sediment is required for pingo growth. Drilling or geophysical investigations possibly could determine if such a relation exists.

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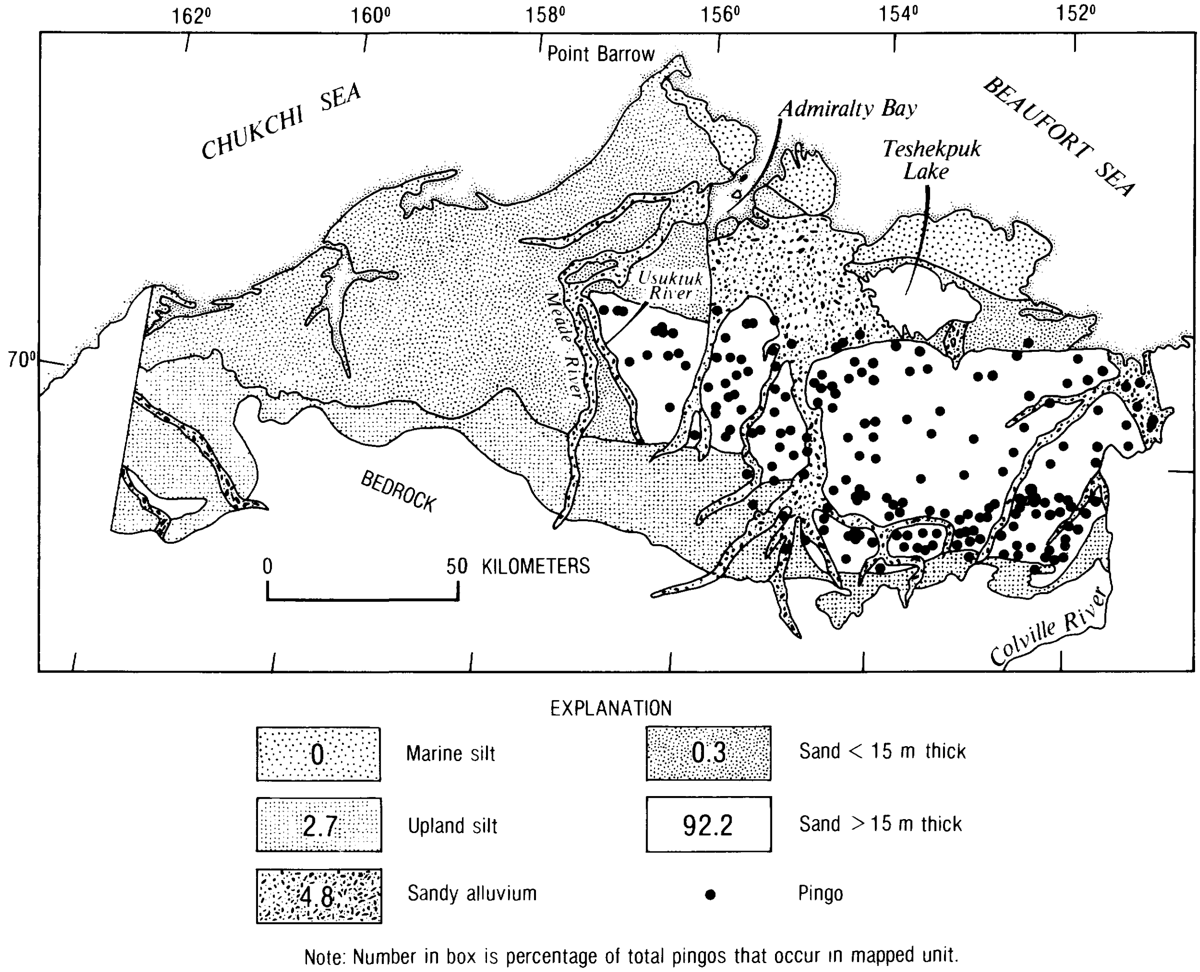

FIGURE 14.—Generalized map of pingo distribution and surficial deposits of Arctic Coastal Plain in National Petroleum Reserve, Alaska. (Surficial deposits modified from Williams and others, 1978).

logical Survey Open-File Report 77–868, 2 sheets, scale 1:500,000.

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Deep thaw lake basins of the inner Arctic Coastal Plain, Alaska

By John R. Williams and Warren E. Yeend

Much attention has been given to the oriented lakes of the Alaskan Arctic Coastal Plain in the Barrow area (Carson and Hussey, 1962; Brown, 1965; Sellmann and others, 1975). However, except for studies by Anderson and Hussey (1963) and by Livingstone, Bryan, and Leary (1958), relatively little information has been made available on the deeper nonoriented thaw lake basins that are higher than 50 m above sea level in upland silt along the inner edge of the coastal plain. These basins are analogous to the alass thermokarst relief of central Yakutia, USSR (Are, 1973; Solov'ev, 1973) and to basins in the loess deposits south and east of the Yukon Flats, Alaska (Williams, 1962, pl. 42). Thaw lake basins are formed by ground subsidence that takes place when extremely ice-rich permafrost thaws. The thaw process creates individual basins that coalesce to form vast areas of interlocking basins among which stand residual knolls of ground that has not been affected by the thaw-collapse process. Away from rivers, this process is the dominant form of landscape alteration in much of the Arctic and in some subarctic regions.

Natural exposures showing sedimentary structure of the thaw lake basins are rare, but one unusually good exposure on the Topagoruk River (lat 70° N., long 156° 13.5′ W.; 146 km S. 15° E. of Barrow) provides a complete section through a drained thaw lake basin. The basin is located at the northern edge of the upland silt (loess?) south of the escarpment that separates the silt unit from marine, fluvial, and eolian sand of the adjacent part of the coastal plain (fig. 15) (Williams and others, 1977).

In the 20-m-high exposure on the north bank of Topagoruk River about 11 m of lacustrine deposits consisting of finely interbedded peat, silt, silty sand, and very fine sand is exposed above massive silty sand and very fine sand. Two downfolded projections of the lacustrine deposits extending into the underlying sediments suggest that thaw collapse activity continued while the lake deposits were being laid down. A sample of the basal peaty material in one of these downfolded projections was dated at 2,640 ± 85 years (I–10,273 shown on fig. 15). This surprisingly young age implies that deposition of 11 m of sediment in the thaw lake basin was rapid, considering the time interval between drainage of the lake and the present. The section was resampled in 1978, and a confirmatory age determination is to be made. Brown (1965, p. 45) cautions that samples of thaw lake deposits may be contaminated by older organic material from the lake banks; however, the dated sample appeared to be of peaty material that grew *in situ*.

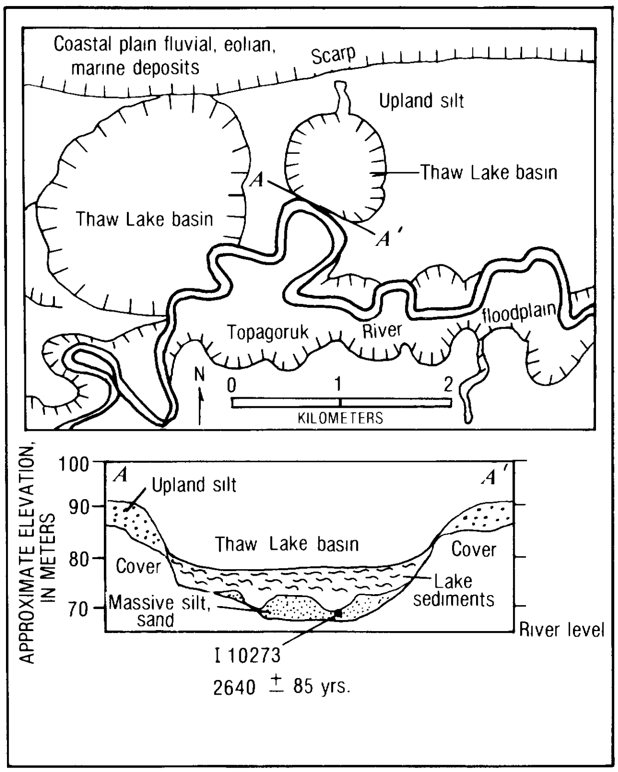

FIGURE 15.—Sketch of thaw lake, Topagoruk River. Hachures point downslope.

The thaw lake basin has a depth of more than 21 m below the original surface of the upland silt. This depth includes the 11 m of lacustrine sediments. Ice content of the upland silt before thaw collapse must have averaged about 78 percent by volume to create the 21-m-deep basin and to fill it to 11 m with lake sediments, assuming a cylindrical model in which the lake sediments were uniformly thick and a soil porosity of 30 percent. This calculation is consistent with similar materials in the ice-complex of the high Tyungyulyunskaya terrace of central Yakutia (Are, 1973, p. 4), where alternating sandy loam, loam, and sand reach a thickness of 75 m and may have a wedge ice content of 50 percent, an interstitial ice content of 50 to 70 percent, and a total ice content approaching 80 percent of the volume of the sediment. Studies of East Oumalik Lake, in upland silt 42 km southeast of the Topagoruk River exposure (Livingstone and others, 1958), showed that ice content of the sediments involved in thaw collapse to form the lake was 68 percent by volume. Examination of isolated exposures of permafrost in the upland silt along the 70th parallel westward toward Icy Cape shows that wedge ice is pervasive and that the sediment between the wedges has a high interstitial ice content. The face that lake sediments in the Topagoruk River section have collapsed suggests that the underlying sediment was also ice rich in places and collapsed under the warming influence of the overlying lake. In contrast to the sandier soils of the coastal plain near Barrow, where the excess ice causing thaw collapse disappears at a depth of about 6 m (Carson and Hussey, 1962, p. 423; Lewellen, 1972, p. 30), the ice-rich permafrost in the upland silt of the Topagoruk River section extended to a depth of at least 21 m below the original surface.

The deep thaw lake basins of the inner coastal plain differ from the oriented thaw lake basins of the northern coastal plain near Barrow in that they are in finer grained materials that are ice rich to a much greater depth than those near Barrow. They are more closely analogous to the deep thaw lake basins of the southern and eastern Yukon Flats district and to those in central Yakutia in similar materials. The age of the deep thaw lake basin deposits on Topagoruk River falls at the younger end of the age range of samples taken from the oriented lake basin deposits near Barrow (Brown, 1965), if the available date proves to be correct.

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Southward-progressing stabilization of Holocene eolian sand on the western Arctic Coastal Plain

By L. David Carter and John P. Galloway

Eolian sand blankets the surface of a large area of the western Arctic Coastal Plain west of the Colville River (Black, 1951; Williams and others, 1977; Williams and others, 1978). Recent work indicates that eolian activity was widespread during latest Wisconsinan and early Holocene time and that the direction of sand transport was southwesterly and westerly from sources east of Judy Creek (Carter and Robinson, 1978a, b). Four exposures at sites within and adjacent to the eolian sand sheet, and nearly across the latitudinal extent of the eolian deposits (fig. 16), allow determination of the time of initial surface stabilization at those sites. At each site, stabilization is recorded by a peaty paleosol. Radiocarbon dates (laboratory numbers shown in parentheses) reported herein suggest that stabilization of the eolian sand and of the surface of the sand source area progressed southward with time.

Site 1, a 3.65-m-high coastal bluff on the south shore of an inlet of Harrison Bay, is at the northern margin of an area of widespread eolian sand. At this locality, eolian sand is overlain by

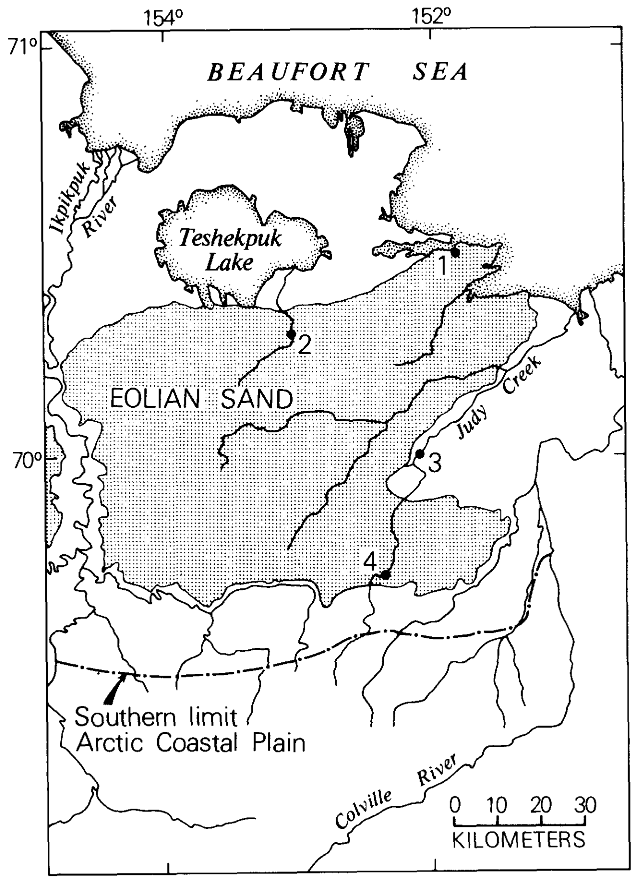

FIGURE 16.—Distribution of eolian sand and location of sites discussed in text.

85 cm of fibrous to very fine grained dark-brown sandy peat. Above the peat is 36 cm of gray fine sand with abundant rootlets, 6 cm of red to brown peat which is woody in places, and 30 cm of tan medium sand containing scattered remains of tundra plants.

Growth of the lower peat records stabilization of the underlying eolian sand. Cessation of peat growth appears to have been caused by development of a small thaw pond because the overlying gray fine sand is identical in character to modern sandy thaw lake deposits in the vicinity. Development of the upper buried peat followed drainage of the pond. The upper 30 cm of sand represents eolian bluff-top accretion.

Radiocarbon dates indicate that development of the lower peat began 9,860 ± 140 (I-10,537) years ago and ceased 7,690 ± 125 (I-10,538) years ago. Wood in growth position in eolian sand 12 km southeast of the site is 9,840 ± 90 (USGS-454) years old, confirming that the age of the base of the peat closely approximates the time of initial sand stabilization in this area.

Twenty-one kilometers south of the northernmost extent of eolian sand is a 27-m-high cutbank (site 2) that records a complex history of eolian deposition and eolian erosion and was described in detail by Carter and Robinson (1978a). The stream cut is across a low hill that is blanketed by the latest Wisconsinan and Holocene sand sheet under discussion. The hill core is a remnant of a dune that was part of an extensive sand sea of unknown age. Sand of the hill core makes up the lower 17 m of the exposure and exhibits large-scale cross-stratification. The blanketing sand lacks large-scale cross-stratification but includes scattered willow stumps in growth position in the lower part and two peat beds and the remains of tundra plants in the upper part. Radiocarbon ages of the lowest peaty paleosol, which is 50 cm thick and occurs 5 m above the base of the sand sheet, indicate that Holocene stabilization first occurred 8,180 ± 75 (USGS-448) years ago. The top of this peat has been dated as 5,250 ± 80 (USGS-379) years old. The upper 4 m of sand, tundra plants, and thin peat are interpreted as eolian bluff-top accretionary deposits associated with development of the cutbank.

Site 3 is a 7-m-high bluff along Judy Creek 5 km east of the eolian sand sheet and within the presumed source area for the eolian deposits. The bluff consists of 1.8 m of dark-gray bedded Pleistocene marine silt, overlain by 4.5 m of brown silty to slightly pebbly fluvial sand. Overlying the Pleistocene deposits is a 35-cm-thick dark-brown fibrous compact peat, and capping the bluff is 25 cm of windblown sand derived from the adjacent flood plain of Judy Creek. Radiocarbon dates of samples from the base and top of the buried peat are 7,025 ± 125 (I-10,539) and 530 ± 75 (I-10,540) years before present, respectively. The age of the base of the peat is a minimum age for the cessation of deflation at this locality. Note that only 35 cm of peat represents about 6,500 years of continuous accumulation. Single radiocarbon dates from thin peat beds should be interpreted with caution.

The character of the upper few meters of the deposits at site 4 is similar to that at site 2; eolian sand at least 5 m thick containing scattered willows in growth position is overlain by a peaty paleosol 61 cm thick, which is overlain by 91 cm of eolian sand that contains scattered remains of tundra plants. The site is near the southern margin of the sheet of eolian sand, and the paleosol is the earliest evidence of sand stabilization at this site. A sample of peat from the base of the paleosol yielded a radiocarbon age of 6,380 ± 115 (I-10,541) years, and a sample from the top is 755 ± 80 (I-10,542) years old.

Figure 17 is a plot of the age of the base of the peaty paleosol at each site against latitude. A southward decrease in the age of the base of the paleosol suggests that surface stabilization progressed southward with time. Dating of paleosols at other localities in the eolian sand is in progress and will test the validity of this conclusion. If southward-progressing stabilization is proved, a possible explanation would be that it was caused by a gradual southward shift of the southern limit of the area in which climate is influenced by the Arctic Ocean. This cooling, humidifying maritime influence moved south as the coastline moved south during the late Wisconsinan and Holocene sea level rise that accompanied deglaciation.

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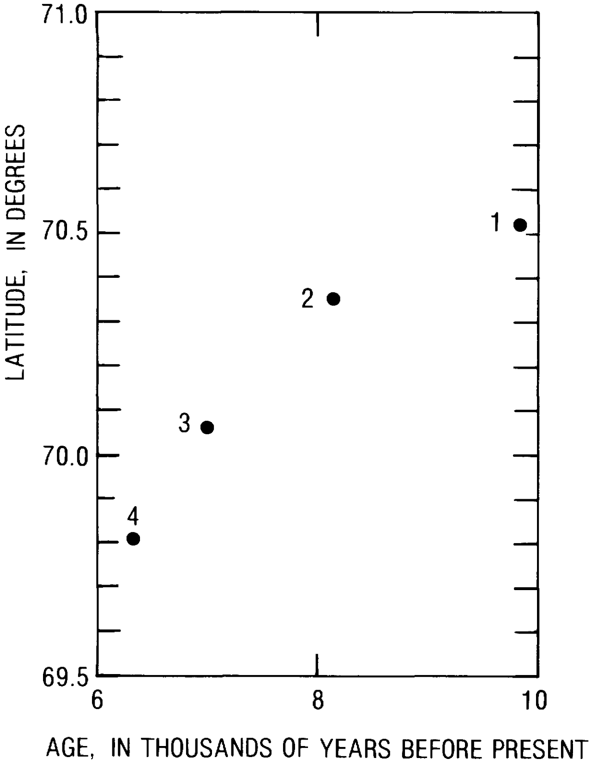

FIGURE 17.—Plot of latitude against radiocarbon age of base of oldest paleosol at each site.

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Paleogeography of a Pleistocene coastline, Alaskan Arctic Coastal Plain

By L. David Carter, Louie Marincovich, Jr., Elisabeth M. Brouwers, and Richard M. Forester

Beach deposits have been identified in an exposure on Fish Creek (site A, fig. 18) on the Arctic Coastal Plain by the abundant remains of an intertidal gastropod. Furthermore, ostracode

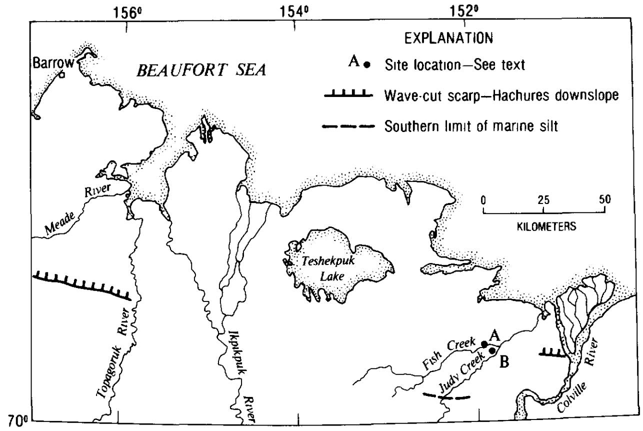

FIGURE 18.—Arctic Coastal Plain, showing sites and features discussed in text.

assemblages at this site, together with the stratigraphy and ostracodes at a nearby site, the distribution of correlative deposits, and the position of probably correlative wave-cut bluffs, suggest a paleogeographic reconstruction of part of an interglacial coastline of Pleistocene age. Deposits such as those on Fish Creek that can be identified as shoreline facies are rare (Williams and others, 1977), and therefore previous studies have determined coastal paleogeography largely by inference (O'Sullivan, 1961; Black, 1964; McCulloch, 1967; Sellmann and Brown, 1973).

The beach deposits are exposed in a 24- to 28-m-high bluff on the north side of Fish Creek that can be divided into four stratigraphic units. The basal unit (unit 1) consists of 3 m of distinctly to indistinctly bedded dark-gray silt containing scattered granules of chert and quartz, sparse sand interbeds and sand-filled burrows, scattered mollusk fragments, and a few thin, woody stems. Overlying the silt is 9 m of brown to gray crossbedded sand to gravelly sand (unit 2) that contains abundant peat and wood. The gravel clasts are predominantly rounded to subrounded chert; clasts of rock types of the Flaxman Formation (Leffingwell, 1919; MacCarthy, 1958; Hopkins and others, 1978) were not observed. This unit contains many mollusk shells, including small, delicate gastropods that are neither broken nor abraded. Above the sand and gravelly sand is 6 to 7.5 m of brown, locally cross-bedded sand to pebbly sand (unit 3) that contains scattered shell fragments. Capping the bluff is 4 to 8 m of eolian sand (unit 4) containing the remains of tundra plants and at least one buried peaty horizon.

Among the many fossil mollusks recovered from unit 2 were numerous unabraded specimens of the small gastropod *Littorina* cf. *L. sitchana* Philippi, 1845. All of the approximately 100 living species of *Littorina* are adapted for intertidal life, and their bathymetric range extends from less than 1 m below the low tide line to the splash zone above the highest tide level. Most species are subaerially exposed for several hours a day, and their presence demonstrates that the sand and gravelly sand of unit 2 is a shoreline deposit.

Littorina sitchana is reported living from Puget Sound, Washington, to the southern Bering Sea (Dall, 1921). The most northerly modern occurrence of the genus is in the eastern Canadian arctic, where *Littorina saxatilis* (Olivi, 1792) has been reported at about lat 65° N. The specimens from the Fish Creek locality (lat 70° 15.84′ N.) are thus far north of the most northern modern occurrence of the genus and strikingly far removed from the present northern limit of the most closely related species, *L. sitchana*. This strongly suggests interglacial conditions during formation of the beach and, inasmuch as the northern limit of *L. sitchana* probably approximates the southern limit of sea ice, may indicate conditions much warmer than those of today.

The top of the beach deposits at Fish Creek is at an elevation of about 22 m. To the west, a prominent but highly degraded wave-cut scarp occurs between the Meade and Topagoruk Rivers (Lewellen, 1972; Williams and others, 1977). The elevation of the break in slope at the base of this feature is about 20 m. East of Fish Creek, near the head of the Colville River delta, another degraded wave-cut scarp occurs, and the elevation of the break in slope at its base is also about 20 m. It is proposed here that the beach deposits at Fish Creek and the two wave-cut scarps represent a single shoreline, assuming that this large area has not been affected by subsequent differential earth movements.

Fossil ostracodes from the silt (unit 1) beneath the beach deposits include *Cytheramorpha macchesneyi* (Brady and Crossky, 1870), *Cytheropteron montrosiense* Brady, Crossky, and Robertson, 1874, and *Loxoconcha* aff. *L. venepidermoidea* Swain, 1963. *Cytheramorpha* and *Loxoconcha* indicate a nearshore marine or marginal marine environment. In the beach deposits (unit 2), both marine and nonmarine ostracodes are present, but marine species predominate in the lower part and decrease in abundance upward. Most of the marine or marginal marine forms, which include *Heterocyprideis sorbyana* (Jones, 1856), *Paracyprideis pseudopunctillata* Swain, 1963, *Rabilimis septentrionalis* (Brady, 1866), and *Eucytheridea bradii* (Norman, 1863), indicate salinities lower than normal sea water. Among the freshwater species in the beach deposits, *Cytherissa lacustris* (Sars, 1863), *Limnocythere platyforma* Delorme, 1971, *Candona candida* (Muller, 1776), *Candona rawsoni* Tressler, 1957, and *Candona rectangulata* generally live in water having a salinity of less than 5 parts per thousand, and some species suggest the proximity of large or moderate-size lakes and fluvial systems. Only nonmarine ostracodes were identified in the pebbly sands (unit 3) above the beach deposits, and this unit is interpreted as a fluvial deposit.

On the south side of Fish Creek, 4.5 km southeast of the beach deposits, is a 9-m-high bluff (site B, fig. 18) that also provides important paleoenvironmental information. From the base of the bluff, 1 m of silt grades upward through silt with layers, lenses, and pods of fine brown sand into fine to medium brown sand with pods of clay, and then into 5 m of fine to medium sand with scattered pebbles. The transition zone from entirely silt to entirely sand is about 1.2 m thick. Enclosed within the sand near its top is laminated silt that contains abundant moss and tiny fresh-water clams. The bluff is capped by 1.5 m of Holcene peat and thaw lake deposits.

Both the basal, fine-grained unit and the transition zone at site B contain marine ostracode faunas like that described for the beach deposits (unit 2) at site A and document low salinity, possibly estuarine, conditions. The overlying 5-m-thick sand contains a fresh-water ostracode fauna like the one in the beach deposits at site A, and the fauna in the laminated silt at the top of the sand includes species that inhabit shallow bodies of quiet water such as abandoned channels. The ostracodes at site B thus record a change from brackish marine, perhaps estuarine, conditions to an environment characterized by large slow-moving streams.

Marine silt overlain by fluvial sand and believed to be correlative with the deposits at site B can be traced on Judy Creek southward from its confluence with Fish Creek for about 30 km (fig. 18). At the southernmost limit of exposure the top of the silt is at an elevation of about 20 m, about the same as the elevation of the top of the beach deposits at site A. The top of the sand forms an exceptionally flat plain that maintains an elevation of about 30 m from just south of the beach deposits to about 6 km south of the limit of marine silt.

On the basis of the lithology, stratigraphy, and faunas of the deposits, and the surface features of this broad area, the beach deposits at Fish Creek are interpreted to be part of a bay- or estuary-mouth barrier or spit system. During the early stages of growth of this system, marine silt was deposited behind the beach. Later, fluvial sands entered and eventually filled the embayment and buried the beach deposits. The interval of Pleistocene time during which this coastal system existed is unknown, but we prefer a middle Pleistocene age because of stratigraphic relations with younger and older Pleistocene marine deposits of the Arctic Coastal Plain.

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Paleoenvironmental interpretation of a fossil insect fauna from bluffs along the lower Colville River, Alaska

By Alan V. Morgan,[4] Anne Morgan,[4] and L. David Carter

Study of an insect fauna collected from unconsolidated deposits exposed in steep bluffs along the lower Colville River has determined the environment of deposition of the insect-bearing bed. The deposits were chosen for study because they contain fossil logs which at various sites along the bluffs have been identified as *Larix* (larch) (O'Sullivan, 1961), *Picea* (spruce), and *Abies* (fir) (R. C. Koeppen, written commun., 1976, 1978). The presence of these logs in a treeless tundra region suggests that environmental conditions during deposition of the materials differed from those of today. Furthermore, the youngest known occurrence of fir in northern Alaska is Miocene (Hopkins and others, 1971), and thus the deposits described in this report may include the oldest unconsolidated beds of the Colville River region.

The sample site is about 19 km north of the confluence of the Anaktuvuk and Colville Rivers at lat 69° 42.95′ N, long 151° 31.45′ W., where 30 m of unconsolidated materials rests on 40 m of Cretaceous bedrock. The basal unit of the unconsolidated deposit is a 6-m-thick, fining-upward sequence of trough crossbedded gravel and sand containing abundant detrital wood and peat. Logs as large as 20 cm in diameter occur in the lower 2 m of this unit. Wood identifications, however, have not yet been accomplished for this site. Overlying the crossbedded gravel and sand is 4 to 5 m of

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evenly bedded silt and sand with concentrations of fine, detrital peat. The upper 20 m of the bluff is obscured by slump but appears to consist of silt and very fine sand that is part of the "Foothill Silt Unit" of O'Sullivan (1961) and of the unit termed Upland Silt by Williams and others (1977).

The insect fauna was extracted from a 3-kg sample collected from a layer of detrital woody peat about 4.5 m above the base of the unconsolidated deposits. The sample was washed in warm water and the organic residue trapped on a 300-μm sieve. The fossil fragments were concentrated by a process described by Morgan and Morgan (1979), sorted in alcohol, and mounted on standard micropaleontological slides. Many invertebrate groups were represented, including ostracodes, oribatid mites, cladoceran ephippia, and numerous insect fragments. Diptera (flies) were represented by larval head capsules of chironomid midges, Trichoptera (caddis flies) by frontoclypeii and other larval head sclerites, and Hemiptera (bugs) by fragments of Corixidae. The largest order present, both numerically and in species diversity, was Coleoptera (beetles). A preliminary faunal list is given in table 3. Although many specimens have been identified only to the generic level, data from these and the small number of individuals that so far have been specifically identified provide some information about the paleoecology of the site. The presence of fresh water is indicated by the aquatic beetle genera *Helophorus*, *Deronectes*, *Colymbetes*, and fragments of Agabiini, together

TABLE 3.—*Preliminary faunal list from site 78ACrII-75, Colville River, Alaska*

- INSECTA
  - Coleoptera
    - Carabidae
      - *Dyschirius* sp.
      - *Asaphidion alaskanum* Wickh.
      - *Bembidion* (2) spp.
      - *Pterostichus nearcticus* Lth.
      - *P.* (*Cryobius*) *brevicornis* Kby.
      - *P.* (*Cryobius*) *nivalis* Sahlb.
      - *Amara bokeri* Csiki
      - *Amara* sp.
    - Dytiscidae
      - Agabiini ? Genus
      - *Colymbetes* sp.
      - *Deronectes* sp.
    - Hydrophilidae
      - *Helophorus* sp.
    - Staphylinidae
      - *Megarthrus* sp.
      - *Bledius* sp.
      - *Arpedium* sp.
      - cf. *Lesteva* sp.
      - *Stenus* sp.
      - *Tachinus apterus* Makl.
      - *T. instabilis* Makl.
    - Chrysomelidae
      - *Chrysolina* sp.
      - ? Genus
    - Curculionidae
      - *Apion* sp.
      - 7 ? Genera
- INSECTA (Con't.)
  - Trichoptera
    - ? Genus
  - Heteroptera
    - Corixidae
      - ? Genus
  - Diptera
    - Chironomidae
      - ? Genus
- ARACHNIDAE
  - Acari
    - Oribatidae
      - ? Genus
- CRUSTACEA
  - Notostraca
    - *Lepidurus* sp.
  - Cladocera
    - *Daphnia* sp.

with the remains of caddis, *Daphnia* ephippia, the corixid bugs, ostracodes, and the crustacean *Lepidurus*. *Lepidurus* inhabits temporary ponds and probably belongs to the species *arcticus*, but the diagnostic telson fragments were not found in the sample. Beetle species that inhabit silty to sandy substrates, commonly bordering water, include *Stenus*, *Bledius*, and *Dyschirius*.

Lack of detailed information on the ecology and distribution of much of the modern arctic fauna imposes limitations upon many of the paleoecological interpretations. However, a consistent ecological picture emerges from the small species list from the site (table 3). The carabid beetles *Pterostichus nearcticus*, *P. (Crybius) nivalis*, and *Amara bokeri*, together with the staphylinid beetle *Tachinus apterus*, are obligate tundra species. *A. bokeri* and *P. nearcticus* have both been found in flood-plain areas, *A. bokeri* in sandy areas subject to flooding by the Colville River at Umiat, and *P. nearcticus* on sandy soil under driftwood in grassland in the Anderson River delta, N.W.T. *P. (Cryobius) nivalis* has been recorded from dry tundra sites in Alaska and eastern Siberia (Lindroth, 1966). *T. apterus* has been found on *Betula nana* (dwarf birch) and flowers of wild celery (Campbell, 1973) but almost certainly inhabits decaying plant and animal material.

Pterostichus (Cryobius) brevicornis is the most widely distributed of all *Cryobius* species, ranging across North America to Labrador and as far south as the Gulf of St. Lawrence in Quebec and Gillam in Manitoba. An isolated assemblage also exists in the western Lake Superior basin. These beetles occur on rather dry tundra meadow ground, commonly among grass and leaves. They have also been recorded from forested areas, mostly near timber line, and are associated with alder at some sites (Lindroth, 1966). *T. instabilis* has been found under moose dung and in leaf litter near streams. This last habitat is somewhat similar to that of *Asaphidion alaskanum*, which has been recorded from the seasonally flooded zone of the Meade River among dead leaves and drift material under rather high *Salix* (willow) bushes. Although *A. alaskanum* is found along the margins of many rivers and brooks, Lindroth (1963) describes it as an inhabitant of dry ground. This species is regarded as a true member of the tundra fauna even though it ranges into the conifer zone, and the same may be said of *T. instabilis*.

In summary, the depositional environment of the detrital peat in the basal unit of the Colville bluffs is regarded as a backwater (marginal channel) beside a major waterway. All the aquatic species indicate quiet or slowly moving water, and velocities required to move the much larger wood fragments presumably were only achieved at flood stage. The strand line debris of twigs and leaf litter was inhabited by a number of species mentioned above, and certain of these may have ranged from nearby more xeric areas. The large number of weevils, at least seven species, and the chrysomelids indicate a nearby vegetation cover. The site was located in a tundra area, although the insect fauna indicates that conifers were not too distant. Summer temperatures probably were slightly warmer than present, but only by 1° or 2° C. Thus, although these deposits may be as old as Miocene, they contain insects that include many elements of a modern tundra fauna. In this regard, the data support studies on the Seward Peninsula which postulated that a tundra environment similar to that of the present had evolved by early Pleistocene time (Matthews, 1974).

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TABLE 4.—*Radiocarbon age determinations from the Beaufort and Chukchi Sea coasts*

Laboratory Number	Location	Latitude N & Longitude W	Material	Determination	Significance
USGS-132	Borehole at center of Prudhoe Bay	70°20.9' 148°19.3'	Wood	490 ± 90	This sample dates a moment shortly after the flooding of a large thaw lake to form Prudhoe Bay.
USGS-192	Borehole 3 km seaward from Reindeer Island	70°30.6' 140°18.0'	Bulk sediment	18,000 ± 170	Expected to date overconsolidated clay but seems too young.
USGS-210	Borehole 7 km from mainland shore of Stefansson Sound	70°25.8' 148°26.6'	Detrital peat	34,000 ± 2100	Sample comes from top of alluvium beneath glacial outwash, from a level that, by correlation, should be considerably older than USGS-249. True age of this sample may be considerably greater than 34,000.
USGS-249	Borehole 3 km from mainland shore, Stefansson Sound	70°42.2' 148°33.5'	Detrital peat	42,800 ± 1440	Dates widespread detrital peat layer interspersed in glacial outwash. Small sample from same horizon in Univ. Alaska hole OH-3370 dated 22,300 ± 1200 (Au=115).
USGS-499	4.5-m terrace, Kaolak River	70°05'00" 159°40'15"	Wood	1,730 ± 40	Dates alluviation to form lowest terrace of Kaolak River.
USGS-500	Foreset beds in 3.5-m terrace at mouth of Kaolak R.	70°07'19" 159°41'00"	Twigs	1,170 ± 45	Dates 3-m storm surge affecting valleys draining into Wainwright Inlet.
USGS-501	Triangulation Station Point 1.0 km southwest of Cape Halkett	70°47'45" 152°12'00"	Peat	3,130 ± 70	Dates base of Holocene thaw-lake deposits.
USGS-503	Triangulation Station Point 1.0 km southwest of Cape Halkett	70°47'45" 152°12'00"	Peat	2,930 ± 50	Dates in-situ peat accumulated after thaw lake was drained and provides measure of duration of lake on this site. Also provides estimate of age of ice wedges 2.5-3.0 m wide.
USGS-505	Gravel pit along lower Put River, Prudhoe Bay	70°17'25.5" 148°31'00"	Peat	26,300 ± 370	Dates the higher and younger of two interstadial or interglacial horizons interbedded with gravel, probably outwash from the Sagavanirktok River.
USGS-506	Bluffs at inner edge of Kasegeluk Lagoon, 1.2 km south of Akeonik	70°16'06" 161°53'29"	Twigs and grass	490 ± 50	This detrital peat from an ice-wedge pseudomorph at base of sandy and gravelly thaw-lake deposits dates existence of the lake.
USGS-509	Left bank of Sagavanirktok River 1.75 km below highway bridge	70°15'46.5" 148°16'42"	Peat	2,270 ± 120	Dates base of thaw-lake deposit resting on terrace alluvium 3 m above present level of Sagavanirktok River. Two meters of aeolian sand have accumulated on river bank since deposition of this peat.
USGS-517	Right bank of Kuk River at head of delta	70°13'55" 159°47'00"	Twigs	10,600 ± 180	Detrital peat in ice-wedge pseudomorph at base of thaw-lake sediments from early Holocene warm period. Contains willow stems at least 5 cm diameter.
I-10328	Low bluffs 1.1 km southwest of Nokotlek Point	70°18'45" 161°03'00"	Detrital peat	9,125 ± 150	Basal peat in the deposits of the lower and older of two successive thaw lakes. Establishes that two lakes can have existed on same site within Holocene time and, with I-10329, shows that older lake existed for considerably less than 3,000 years.
I-10329	Low bluffs 1.1 km southwest of Nokotlek Point	70°18'45" 161°03'00"	Twigs	6,234 ± 120	Dates basal 10 cm of 60-cm detrital peat representing younger of two successive thaw lakes. Ice wedges 20-70 cm wide (M_d=40 cm) formed since lake was drained.
I-10330	Low bluffs 0.5 km southwest of Nokotlek Point	70°19'33" 161°01'24"	Peat	8,275 ± 135	Dates basal 5 cm of 1.9-m-thick deposit representing peat accumulated in low-center ice-wedge polygons. Provides a minimum date for time of inception of low-center polygons and basis for estimating rate of peat accumulation at Nokotlek Point.

Radiocarbon dates from the Beaufort and Chukchi Sea coasts
By D. M. Hopkins and S. W. Robinson

Radiocarbon methods were used to date 22 samples from the coast and continental shelf of the Beaufort and Chukchi Seas, as a contribution to the Outer Continental Shelf Environmental Assessment Program. The dates, which are listed in table 4, show that:

(a) Leeward deposits of eolian sand measured at two places on bluffs along the western sides of the Canning and Sagavanirktok Rivers accumulated at rates of 0.9 and 1.25 mm/year. The active cliff-head dunes were initiated within the last 5,000 years in the three places where relevant samples have been dated.

(b) A leeward sand accumulation on the east end of Flaxman Island no longer has a source and is no longer active. Evidently the sand accumulated at a time when sea level was lower and the Staines River flowed through the present site of Leffingwell Channel between Flaxman Island and Brownlow Point. Dated samples indicate that the leeward sand accumulation on Flaxman Island began to develop a few centuries prior to 4,900 years ago and thus that the river was flowing through the area at that time. Deposition ceased shortly after 2,400 years ago, probably because rising sea level inundated Leffingwell Channel.

(c) A white or pink volcanic ash recognized

TABLE 4.—*Radiocarbon age determinations from the Beaufort and Chukchi Sea coasts*—Continued

Laboratory Number	Location	Latitude N & Longitude W	Material	Determination	Significance
I-10331	Low bluffs 0.5 km southwest of Nokotlek Point	70°19'33" 161°01'24"	Peat	9,535 ± 150	Dates cryoturbated stringers of fine-grained peat in colluvium 25 cm below base of low-center polygon peat (I-10330). Provides maximum date for inception of low-center polygons at Nokotlek Point.
I-10332	Low bluffs 0.2 km southwest of Nokatlek Point	70°19'42" 161°01'00"	Twigs	8,435 ± 160	Dates basal 10 cm in thaw-lake deposits 1.5 m thick. Sample collected within 50 m of former lake margin and thus thought to have been deposited shortly before lake was drained. Ice wedges 35-125 cm wide (M_d=85 cm) formed since lake was drained.
I-19368	Shore of tidal mudflat representing breached thaw lake 10 km southwest of Wainwright Inlet	70°31'30" 160°17'00"	Detrital peat	9,180 ± 150	Dates basal sediments in deposits of an older thaw lake. Ice wedges 70-250 cm wide (M_d=120) have formed since lake was drained.
I-10369	Mainland shore of Canning Lagoon, 0.4 km west of mouth of eastern branch of Canning River	70°04'42" 145°35'00"	Detrital peat	3,945 ± 115	Sample collected 1 cm below white ash layer in windblown sand sequence derived from Canning River bars. Gives minimum age for beginning of accumulation of windblown sand and, with I-10370, brackets age of ash.
I-10370	Mainland shore of Canning Lagoon, 0.4 km west of mouth of eastern branch of Canning River	70°04'42" 145°35'00"	Twigs and detrital peat	3,315 ± 95	Sample collected 5 cm above white ash layer. With I-10369, brackets age of ash.
I-10371	East end of Flaxman Island	70°10'34.5" 145°56'48"	Detrital peat	4,890 ± 230	Sample collected at depth of 3.6 m in 4.0-m layer of windblown sand derived from river bars when sea level was low and west fork of Canning River flowed through Leffingwell Channel. Sample collected 5 cm above an ash layer thought in field to be same as ash bracketed by I-10369 and I-10370.
I-10372	East end of Flaxman Island	70°10'34.5"	Detrital	2,375 ± 175	Sample collected at depth of 0.45 m in 4.0-m layer of windblown sand. Provides maximum date for drowning of Leffingwell Channel by rising sea level.

in Holocene deposits along the eastern Beaufort Sea coast is probably about 3,700 years old. The ash layer is bracketed by samples dated as 3,300 and 3,950 years old at the mouth of the east branch of the Canning River. However, a sample, which according to our records came from above the ash on Flaxman Island, yielded a radiocarbon age of 4,890 years. Other samples from the same section await radiocarbon analysis, and, when complete, these analyses will permit us to evaluate the significance of the seemingly anomalous Flaxman Island date. Radiocarbon samples bearing on the age of the ash were also collected in Holocene alluvium of the Putuligayuk River but have not yet been dated. It is hoped that, when dated, this ash layer will be useful in making field estimates of the age of young eolian, thaw-lake, alluvial, or archaeological deposits elsewhere along the eastern Beaufort Sea coast.

(d) Peat accumulates in low-center polygons at Nokotlek Point near Icy Cape at a rate of about 0.25 mm/year. Peat deposits there are about as thick as any seen along the Chukchi or Beaufort Sea coasts, so this may be a fair approximation of the general rate of peat accumulation in marshes of the North Slope.

(e) A 1.5-m-thick sequence of thaw-lake deposits near Cape Halkett accumulated within a 200-year interval, and a site south of Nokotlek Point has lain within the basin of two successive thaw lakes during the last 9,100 years. These observations are consistent with observations in the Old Crow Flats (W. W. Pettapiece, *in* Lowden and others, 1977, p. 17) and on the Seward Peninsula (D. M. Hopkins, unpub. data, 1978) that individual thaw lakes rarely persist on the landscape longer than 1,500 years.

(f) Active ice wedges near Cape Halkett have been growing at a rate of about 1 mm/year, but active ice wedges in the Wainwright-Nokotlek Point area are growing much less rapidly, at a rate of only about 0.2 mm/year (fig. 19). This rate is consistent with experimental studies that indicate average growth rates of about 1 mm/year near Point Barrow and much less than 1 mm/year on Garry Island at the mouth of the Mackenzie River (MacKay and Black, 1973, p. 188).

(g) A prograded deltalike deposit at the mouth of the Kaolak River seems to provide the record of a late summer flood and storm surge about 1,000 years ago that raised water level at least 3 m in the Kuk River estuary system (Hopkins and others, 1979).

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The Cretaceous Nanushuk Group of the western and central North Slope, Alaska

By A. C. Huffman and T. S. Ahlbrandt

The Nanushuk Group of Albian to Cenomanian (Early and Late Cretaceous) age is a predominantly regressive sequence of marine, transitional, and nonmarine sedimentary rocks that filled the Colville trough from the southwest and south. Field and laboratory work in 1977 and 1978 has confirmed that the Nanushuk Group was deposited in two depocenters, both of which have been interpreted to be river-dominated delta systems. The deltaic sediments of the Nanushuk were deposited on top of prodelta mud and silt of the lower to middle Albian (Lower Cretaceous) Torok Formation, which filled the Colville trough from the west and southwest. The basal marine sedimentary deposits of the Nanushuk grade into and inter-

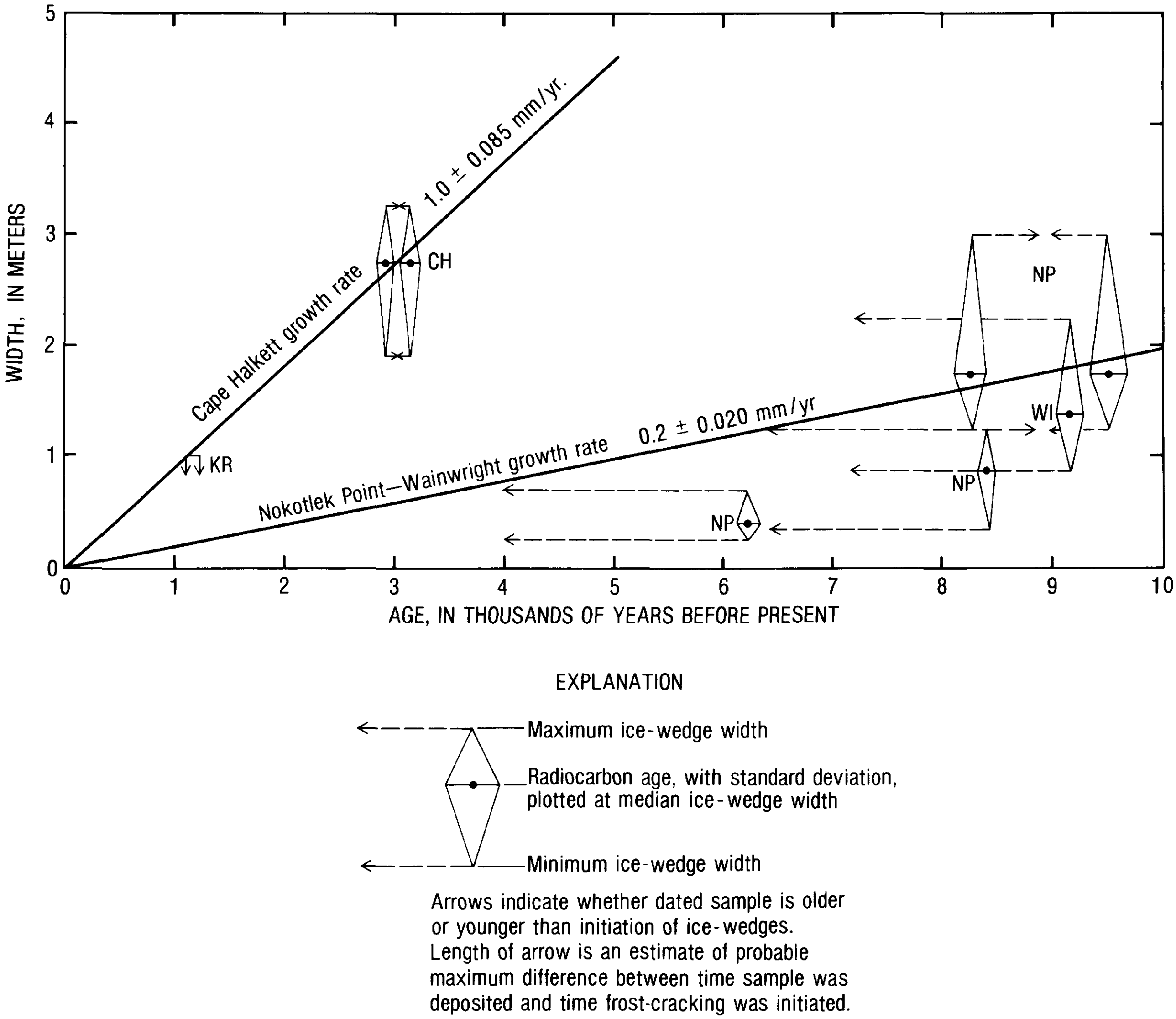

FIGURE 19.—Rates of ice-wedge growth at Cape Halkett (Beaufort Sea) and in the Nokotlek Point-Wainwright area (northern Chukchi Sea). CH, Cape Halkett; KR, Kaolak River (approximate measurement only); NP, Nokotlek Point; WI, Wainwright Inlet.

tongue with shale of the Torok Formation below and with nonmarine deposits of the Nanushuk Group above. The transition from marine to nonmarine is characterized by intertonguing marine and nonmarine facies over an interval 150 to 600 m thick and is overlain by fluvial and lacustrine deposits in the southern and western areas. To the northeast, the regressive marine and transitional deposits are overlain by a transgressive marine sequence, the basal part of which is included in the Nanushuk Group.

The western (Corwin) delta was the primary focus of the 1977 field season and the following winter's laboratory work. Summaries and analyses of the field data as well as the laboratory results are being published as U.S. Geological Survey Circular 794 (Ahlbrandt, 1979). Several lines of evidence cited in the circular, such as grain size, transport directions, and sand percentages (fig. 20), total thickness (Ahlbrandt and others, 1979), sand composition (Huffman, 1979; Bartsch-Winkler, 1979), and relative ages (Scott and Smiley, 1979), strongly suggest that

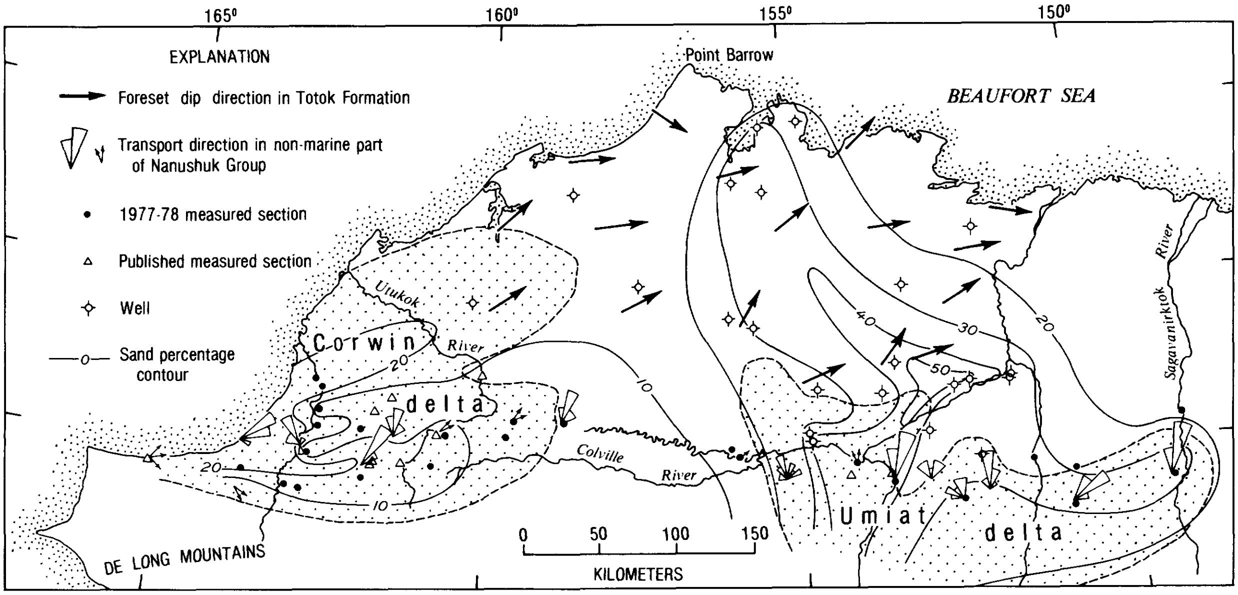

FIGURE 20.—Western and central North Slope showing generalized sand percentage contours for Nanushuk Group and transport directions from nonmarine part of Nanushuk Group and prodelta deposits of the Torok Formation.

the source of the Corwin delta was to the south and west, perhaps in the vicinity of the De Long Mountains, Tigara uplift, and Herald arch (Mull, 1979). These results agree well with seismic studies (Bird and Andrews, 1979), which show that the prodelta mud of the Torok Formation also filled this part of the Colville trough from the southwest.

Sandstone of the Nanushuk Group in the Corwin delta is classified as a sedimentary litharenite, which has been subjected to diagenetic alteration detrimental to reservoir quality (Huffman, 1979; Bartsch-Winkler, 1979). With very few exceptions, the interstices are choked with clay and calcareous mud, and much of the sandstone in the nonmarine part of the section is tightly cemented with sparry calcite related to both depositional environment and source material (Huffman, 1979). Characteristic of the sandstone throughout the section are lithic fragments of chert and calcareous and argillaceous rocks, many of which were squeezed during compaction to fill even the smallest pores (Bartsch-Winkler, 1979). The relative abundance of these constituents is correlated with the stratigraphic sequence exposed by progressive erosion in the source area of the Corwin delta (Huffman, 1979). Sandstone constitutes only 20 percent or less of the entire Nanushuk Group in the Corwin delta (fig. 20), and, perhaps because of rapid subsidence of the trough and high sedimentation rates, sand bodies are very rarely stacked.

Paleontologic studies suggest an early to middle Albian age for the Corwin delta but have otherwise met with only limited success. Pollen and spore recovery from outcrop samples has been generally poor, but, when combined with plant megafossil material, it may yield a workable palynologic zonation within the Nanushuk Group (Scott and Smiley, 1979). The poor quality and quantity of palynological material may be partially explained by the high thermal history of the western North Slope, as indicated by high reflectance and thermal alteration index values (Magoon and Claypool, 1979). Preliminary results of foraminifer and dinoflagellate studies suggest very shallow water depths for most of the marine and transitional sediments of the Nanushuk Group in the Corwin delta (Sliter, 1979).

The 1978 field effort was concentrated on the Umiat delta of the central North Slope. This delta has been described previously as a high-constructional (river-dominated) delta (Fisher and others, 1969), but very little of the total system is visible in outcrop, and most of that is along depositional strike. Sand percentage contours (fig. 20) yield forms that suggest much of the Nanushuk Group in this area may have been strongly affected by wave energy and longshore drift. Seismic studies (Bird and Andrews, 1979) indicate that the prodelta mud of the Torok Formation filled this part of the Colville trough from the west with a minor southwest component, evidence that agrees well with the general shape reflected by the sand percentage contours of figure 20.

Preliminary results of the outcrop studies in the central North Slope indicate paleotransport directions generally from the south (fig. 20), thus suggesting a source terrane for the Nanushuk Group of the Umiat delta quite separate from that of the Corwin delta. This suggestion is confirmed by both field observations (Ahlbrandt and others, 1979) and petrographic studies (Bartsch-Winkler, 1979; Fox, 1979), which show that sandstone from the Umiat delta contains more quartz, quartzite, and metamorphic rock fragments than does the sandstone of the Corwin delta, which is enriched in carbonate and argillaceous rock fragments. A second significant difference in the two systems is the high sand percentage in the Umiat delta, where 40 percent sand for the entire Nanushuk section is common, compared to the low sand content ($\leqslant$20 percent) in the Corwin delta. The presence of the 900- to 1,500-m-thick quartzite- and quartz-rich Kanayut Conglomerate and the phyllitic Hunt Fork Shale in the Brooks Range south of the Umiat delta and the absence of any comparable unit southwest of the Corwin delta may explain many of the lithologic differences between the two systems. A third significant difference between the two deltas is the generally higher porosity and permeability of sediments of the Umiat delta. A fourth difference is the presence of porous, permeable beach sand in the outcrop belt of the Umiat delta; the presence of beach sand is consistent with the character of the source terrane and the suggested wave activity during deposition of these sediments.

Preliminary micropaleontologic results, based on examination of borehole samples, indicate that recovery is fairly good in the central North Slope and that a zonation utilizing dinoflagellates and foraminifers is possible (May, 1979; May and Stein, 1979; Sliter, 1979). The Nanushuk Group in the Umiat delta is apparently middle Albian to Cenomanian in age, and most of the Nanushuk Group marine sedimentary rocks were deposited in deeper water than were those in the Corwin delta.

Reconnaissance work east of the Sagavanirktok River indicates that the Nanushuk Group changes character rapidly to the northeast and loses its identity completely beyond the Ivishak River. Coeval rocks consist of a thick sequence of apparently deep-water marine shale, mudstone, marl, and sandstone exhibiting many turbidite features. This rapid facies change suggests that the sediments of the Nanushuk Group in the vicinity of the Sagavanirktok River were deposited very close to the edge of a continental shelf. Reconnaissance work further east in the Arctic Wildlife Range indicated that rocks lithologically similar to the Nanushuk Group are absent in that area. Paleontologic and petrographic studies are currently in progress on material collected from sites previously identified as possible Nanushuk equivalents (Detterman and others, 1975).

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Vegetation mapping of the National Petroleum Reserve in Alaska using Landsat digital data
By Leslie A. Morrissey and R. A. Ennis

The National Petroleum Reserve in Alaska (NPRA) is the subject of an intensive planning effort as directed by the National Petroleum Reserves Production Act of 1976 (PL 94–258). The U.S. Geological Survey (USGS) is responsible for compiling a resource inventory in compliance with Section 105B, Environmental Impact Assessment, while the Bureau of Land Management is responsible for Section 105C, Land Use Study. Both efforts need a comprehensive vegetation map of the region. With funding from the Environmental Impact Analysis Program of the USGS, the Geography Program mapped the vegetation of the 97,000-km^2 NPRA using Landsat digital data. The project was also a prototype for producing USGS land use and land cover maps from Landsat digital data. If successful, these techniques can be applied in other high-interest areas of the state gradually to build up a series of land use and land cover maps for Alaska.

Techniques for computer-aided analysis have been developed to create maps and statistical data from Landsat digital data. Digital analysis techniques developed by Geography Program analysts at Ames Research Center in California utilized several computers for the NPRA mapping project. Access to several computer systems made it possible to use the most efficient system for each specific processing task.

The EDITOR software package, developed by the Center for Advanced Computation (CAC) at the University of Illinois at Urbana-Champaign, provided the mainstay for the interactive image analysis capability. The EDITOR package is available on the TENEX (modified DEC System PDP-10) at Bolt, Beranek, and Newman in Boston and on the ILLIAC IV parallel processing computer at Ames Research Center.

Natural groupings of the multispectral data from the four bands were established using cluster analysis procedures, first implemented for remote sensing purposes at the Laboratory for Applications of Remote Sensing (LARS) at Purdue University and later incorporated into the EDITOR system by CAC. A data reduction program available in EDITOR enables clustering of an entire Landsat scene on the ILLIAC IV to define a number of internally homogeneous spectral classes. The large sample of data examined in clustering increases the probability of sampling unique or nonextensive land cover types. Each clustering provided a set of statistics, including means and covariance matrix of the four bands, for each cluster. A maximum likelihood classification was performed on the CDC 7600, assigning each pixel to the specific cluster it most nearly resembled. Ten cloud-free Landsat scenes were processed in this way to cover NPRA fully.

Evaluation of the classifications required field reconnaissance. The Bureau of Land Management provided logistic support for the four-week field season in the summer of 1977. Two strategies were chosen for verifying classification results. Line-printer maps were used for individual class identification, and color-coded enlargements of the digital classifications were used for regional land cover verification.

The results of the fieldwork and preliminary identification of the spectral classes provided the basis for the NPRA classification scheme. The classification scheme was based on land cover types that could be delineated optimally with multispectral satellite data. The classification scheme is based on physiognomy, that is, plant communities that are similar in lifeform. The plant communities are described according to dominant species. The land cover classes are Deep Water, Shallow/Sedimented Water, Marsh, Meadow, Mixed Tundra, Tussock Tundra, Dryas, Barrens, Riparian Shrub, and Ice and Snow.

Analysts from the Geography Program accompanied members of the USGS Branch of Alaskan Geology in the field during the summer of 1978. Classification accuracy was verified and the classification scheme further refined.

A color-coded mosaic of the final classification of vegetation within NPRA at a scale of 1:500,000 (along with tabulations of vegetation by township) is being prepared for publication in the USGS Miscellaneous Investigations Map Series. The same data will serve also as the basis for preparation of color-coded vegetation maps of eight quadrangles at 1:250,000. These will be the first in a series of land cover maps derived from Landsat digital data which the Geography Program is planning for Alaska.

Design of airfields in National Petroleum Reserve in Alaska

By Reuben Kachadoorian, F. E. Crory,[5] and R. L. Berg[5]

An integral part of the U.S. Geological Survey's program for the evaluation of the petroleum potential of the National Petroleum Reserve in Alaska (NPRA) is the construction of all-year airfields capable of handling C-130 (Hercules) aircraft. Design and construction problems for the airfields, one at Inigok and the other at Tunalik (fig. 21), were compounded by permafrost and by the constraint that they be built in the winter and in accordance with environmental requirements. To our knowledge, winter construction of such large airfields, 50 m wide and 1,600 m long, for all-year use had not been attempted previously in a permafrost terrain. All other airstrips constructed in the past have required a minimum gravel pad 2.6 m thick.

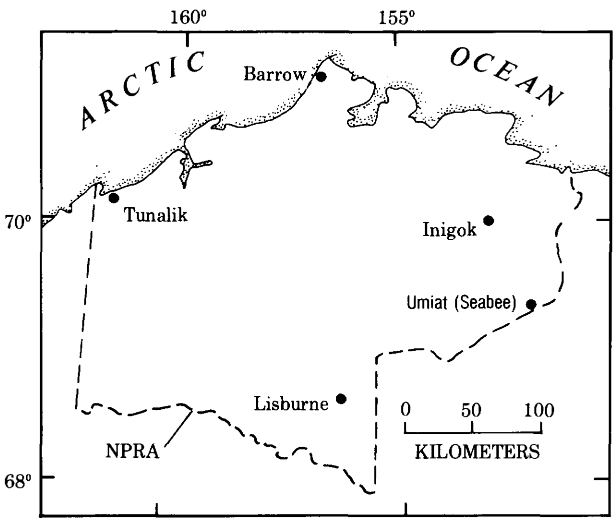

FIGURE 21.—Location of well sites in NPRA: Tunalik, Inigok, Lisburne, and Umiat (Seabee).

In cooperation with the Corps of Engineers (Cold Regions Research and Engineering Laboratory, Hanover, N. H., and the Waterways Experiment Station, Vicksburg, Miss.), a new concept

[5] U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), Hanover, N.H.

was developed for winter construction of airfields. This concept consisted of using local frozen borrow material (sand at Inigok and gravel at Tunalik) as a base course. The base course was overlain by high-density HI-60 styrofoam insulation placed in a single 5-cm layer at Tunalik, and in two layers, each 3.8 cm thick, at Inigok. The insulation in turn was overlain by 45 cm of gravel, the amount required to protect the insulation from damage by compression and breakage under the 16,000-kg/wheel load imposed by C–130 aircraft.

Gravel to construct the Tunalik airstrip was obtained within 10 km of the proposed airfield site. Because of the lack of a local gravel source at Inigok, a 58-km snow-ice road had to be constructed from the airfield site to the confluence of the Kikiakrorak and Colville Rivers, where gravel was obtained to overlay the insulation. A total of 67,000 m^3 of gravel was hauled to Inigok before spring breakup destroyed the snow-ice road.

In March, 1978, while the runways at Inigok and Tunalik were under construction, temperature-sensor (thermocouple) installations were placed at each runway, as follows: (1) two installations beneath the insulation to a depth of 6.5 m, (2) two at the same locations as (1) but with sensors below and above the insulation and in gravel about 15 cm above the insulation, and (3) one in the tundra off the shoulder of each of the runways. After the runways were opened to traffic in late May 1978, the thermal regimes of the runways were carefully monitored to assess the airfield designs. The subgrade beneath the insulation at both Tunalik and Inigok remained frozen throughout the summer of 1978 into freeze-up. Excessive moisture in the gravel overlying the insulation at Tunalik during breakup and the poorly graded gravel overlying the insulation at Inigok created local soft spots in both runways. Once runways were rolled and compacted, however, they performed exceedingly well.

Temperature data collected from March to December 1978 indicate that the maximum temperature immediately below the 7.6-cm-thick insulation at Inigok was –3.3°C. The maximum temperature below the 5-cm-thick insulation at Tunalik was –0.6°C, which no doubt reflects the thinner insulation. Thus, the 5-cm-thick insulation at Tunalik appears to have only a 0.6°C margin before thawing will occur, whereas at Inigok the margin is 3.3°C. We do not expect any substantial thawing at Tunalik because, if the temperature in the subgrade below the insulation were to reach 0°C, the latent heat of fusion in the frozen subgrade materials would provide a large cold sink that would keep the temperature close to 0°C for many weeks. Ground temperatures are being monitored during 1979 at both airfields.

The concept developed for runways at Inigok and Tunalik is being applied to a new temporary airstrip capable of handling C-130 aircraft at the Lisburne well site (fig. 21), where a total of 6.3 cm of insulation in two layers is being used. Design criteria for insulation requirements for the Lisburne site were based on the results of thermal performance of the Inigok runway. Thermocouples will be installed at Lisburne in the same manner as at the Tunalik and Inigok airfields and also will be placed beneath the uninsulated airstrip at Umiat (Seabee) for direct comparison with the three insulated airstrips. Test sections will also be installed at Lisburne to evaluate the thermal efficiency of a single layer of insulation compared to that placed in two layers with staggered joints.

The successful new concept for winter construction of large all-year airstrips at Tunalik and Inigok is also applicable to permanent airfields, roads, and construction pads. This technique allows utilization of only 45 cm of gravel as compared to 2.6 m required to prevent thaw of permafrost beneath noninsulated airstrips suitable for C-130 aircraft. The concept is a significant contribution to arctic construction because it reduces the cost and environmental impact of mining and hauling gravel.

Development and operation of gas fields in the Barrow area

By Robert D. Carter and Robert J. Lantz

Three wells were drilled near Barrow during 1978. Well No. 16, an exploratory well drilled 2.5 km northeast of the South Barrow gas field, was completed as a dry hole. The objective, the Jurassic Barrow gas sand of local usage, was not present because of its truncation by the basal Cretaceous unconformity. No other productive sands were found in the well.

The South Barrow East gas field, discovered by the U.S. Navy, was evaluated further by two development wells, Nos. 17 and 19. Objectives of the wells were to extend the Barrow gas sand production and increase deliverability, to evaluate the Triassic Sag River oil sand of local usage, and to determine, if possible, the boundaries of the field. The drilling program was successful on all counts. Both wells proved to be productive in the Barrow gas sand, and well No. 17 tested a gas-water contact. The Sag River oil sand was cored in both wells and found to be oil saturated. Drill stem tests of the sand in both wells proved disappointing, however, because little free oil was recovered. Test data indicated low productivity. Both wells were exhaustively tested while being completed for production; these analyses are still in progress.

Availability of NPRA data
By Robert D. Carter and Raul J. Madrid

Well logs and histories generated from 1955 to 1972 in the petroleum exploration of NPR–4 (NPRA) by the U.S. Navy were released to the public in June 1978. Well logs and histories for 139 wells are available from: U.S. Department of Commerce, National Oceanographic and Atmospheric Administration (NOAA), National Geophysical and Solar-Terrestrial Data Center (D62), Boulder, Colorado 80303. Among the records available are those of 17 wells, including seven wildcats, in the area of high current interest adjacent to pending offshore lease sale tracts in the Beaufort Sea.

Geophysical data resulting from the 1972–77 Navy exploration have been forwarded to NOAA and will be available to the public early in 1979. Approximately 12,288 km of common data point seismic reflection data, including seismic sections, velocity analyses, shotpoint location maps, and index maps will be open-filed. A companion report based on the data has also been processed by the U.S. Geological Survey and sent to NOAA for release in the spring of 1979. Well logs and histories of six wells drilled by the Geological Survey in 1978 should also be available in 1979.

Water resources of the Noatak River basin
By Joseph M. Childers and Donald R. Kernodle

Hydrologic surveys made by USGS personnel during April and August 1978 provide data to help describe water resources of the Noatak River; this river is important to the economic well-being of the people of Noatak, Kotzebue, and the surrounding region. The Noatak River (fig. 22) is also increasingly being used by visitors from outside the Kotzebue Sound region for recreation, including hunting, fishing, camping, and boating. The Noatak River was chosen for the survey because it is receiving heavier use than other similar rivers in arctic Alaska. The data gathered may help resource planners understand the present characteristics of the waters before possible impacts of increased usage take effect. The hydrologists traveled by ski-equipped plane in April and by motorboat in August. The August survey also provided information helpful to persons plannning boat trips on the Noatak.

The April survey provided data and observations on conditions during late winter in arctic Alaska; this is also the time of annual low streamflow and maximum ice accumulation in this region. An estimated 4m^3/s flowed into Kotzebue Sound from the Noatak River during April 1978. Many spring and open (ice-free) leads were noted along the main course of the river and its tributaries. The open leads were in flowing streams that were warm enough to prevent freezing. A large open lead was noted at Noatak village. Large icings were seen at sites along most of the larger tributaries. In a typical stream, water flowed in discontinuously open leads to an icing. Observations in holes drilled through as much as 2.5 m of ice in the Noatak River channel near Noatak Canyon showed no flow, and the river was frozen solid in some reaches above the canyon. Although measurements of flow were made in several tributaries above Noatak Canyon, these streams were seen to be feeding icings. Downstream, in Lower Noatak Canyon, beneath 0.5 m of snow and 1 m of ice cover, water was 8 m deep and saline, probably having been intruded up the Noatak channel from Kotzebue Sound. Water in the open leads sampled was soft and had low dissolved solids and high dissolved oxygen concentrations. The water was clear and had temperatures of near 0°C.

August measurements showed that the discharge of the Noatak River increased from about 28 m^3/s at its confluence with the Ipnelivik River (600 km above the mouth) to about 280 m^3/s in Noatak Canyon. At this season also, the river water was soft and had low dissolved solids

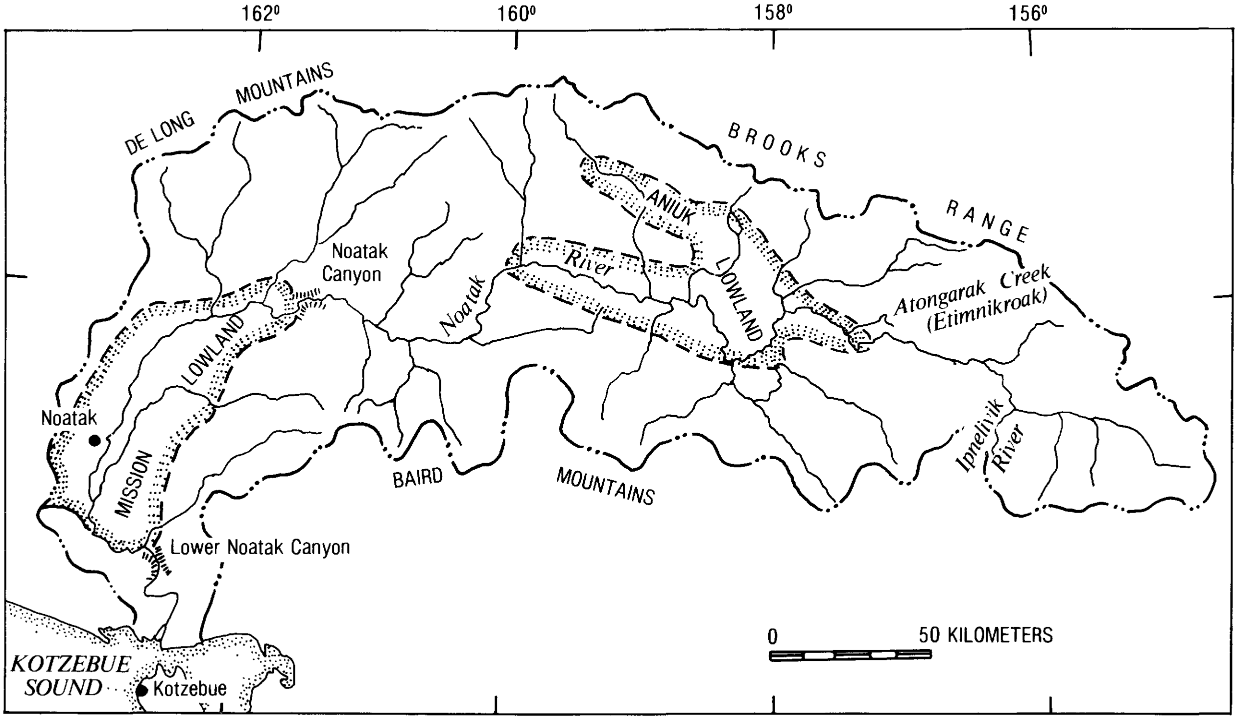

FIGURE 22.—Noatak River basin, Alaska.

and high dissolved oxygen concentrations. The water was cold and clear; one tributary had turbid water, probably as a result of a rainstorm in its drainage, runoff from which was causing some erosion.

The Noatak River provided very good conditions for recreational boating from the Ipnelivik River to the mouth. Pools from 300 to 1,500 m long and having gravel and cobble beds, separated by boulder riffles as much as 100 m long, characterize the Noatak River from the Ipnelivik River to the Eli River. Below the Eli, the Noatak River was wide, deep, and smooth flowing. One 10-km reach of boulder-strewn rapids upstream from Atongarak Creek is called Etimnikroak, or swift water, by the Eskimos. This was the only segment of the Noatak observed during August that might cause a navigational problem for canoers or kayakers.

The August survey included observations of flood and channel erosion evidence along the Noatak River. Most maximum evident flood marks were found close to the tops of channel banks and near the base of mature willows.

The Noatak River channel appeared quite stable except for some bank erosion noted in mostly braided reaches through the Aniuk and Mission Lowlands. Thawing ice masses were exposed in some eroding banks; an ice bank about 1 km long is located about 5 km downstream from Noatak village.

Other information obtained during the surveys includes discharge and water-quality measurements at selected springs, spot depth and water-quality measurements at selected lakes, and estimates of maximum evident flood peak and bankfull channel discharges at selected stream sites. Benthic invertebrates from 15 stream sites have been identified to the family level at this time.

EAST-CENTRAL ALASKA

Metamorphic rock units of the southern part of the Circle quadrangle, east-central Alaska

By Helen L. Foster, Florence R. Weber, and Terry E. C. Keith

Geologic mapping was begun in the southern part of the Circle quadrangle, where several of the metamorphic map units could be traced northward from the adjacent Big Delta quadrangle. Nine distinct metamorphic rock units have been mapped in the Circle quadrangle so far, and it may be possible to subdivide at least one of these units. The rocks range in metamorphic grade from greenschist to amphibolite facies. Their age and stratigraphic relations are not known because fossils have not been found in these rocks in either the Big Delta or Circle quadrangles, except for radiolarians and conodonts in chert associated with ultramafic rocks in the Big Delta quadrangle.

Although quartzite and quartzitic schist are abundant metamorphic rock types in the Circle quadrangle, pelitic schist and gneiss also occur. Staurolite is abundant in some schist, and staurolite-sillimanite and staurolite-kyanite associations are present. A sillimanite gneiss with much altered feldspar, a major unit in the Big Delta quadrangle, extends northward into the southeastern part of the Circle quadrangle. Abundant marble and impure marble interlayers are present in several of the units, but individual marble layers are difficult to identify and can seldom be traced farther than 500 m. Amphibole-bearing layers are also fairly common. A section containing quartzite, kyanite-staurolite-muscovite-biotite schist, amphibolite, and marble resembles that found in the Eielson deep test hole drilled in the northwestern part of the Big Delta quadrangle (Forbes and Weber, 1975, p. 654).

A calcareous phyllite and schist associated with a section characterized by black quartzite has lithologic similarities to some Paleozoic rocks in Yukon Territory and in the northern part of the Alaska Range. Some of the contacts of this rock group are suspected faults. Another section of quartzite, locally referred to as "grit" where it contains small, rounded, clear, bluish-gray quartz grains or "eyes," appears to overlie discordantly some of the units described above and may be the remnant of a large thrust sheet.

Small patches of augen gneiss, associated with light-green calcareous and quartzitic rocks, including garnet diopside skarn, are irregularly distributed in the southeastern part of the Circle quadrangle. Three separate, small, serpentinized ultramafic bodies, which probably have been faulted into contact with the metamorphosed country rocks, have been found. The ultramafic rocks appear similar to those of the Big Delta quadrangle.

Foliations in the metamorphic rocks in the southern part of the Circle quadrangle suggest a northeast-trending antiform. Several small granitic plutons lie along its approximate axis.

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Big Windy Creek hot springs, Circle A–1 quadrangle, Alaska

By Terry E. C. Keith and Helen L. Foster

A small hot spring area in the canyon of Big Windy Creek in the northwest corner of the Circle A–1 quadrangle was very briefly visited in July 1978. G. A. Waring (1917) first recorded the occurrence of the springs, although he did not visit them. The springs are difficult to reach because of the remoteness of the area and because the canyon of Big Windy Creek is very steep sided with many large granitic boulders filling the creek. The spring area occurs near the north edge of a small granitic pluton, which has intruded regionally metamorphosed rocks including thinly layered marble and quartz-biotite schist.

Most of the springs flow out from the face of a nearly vertical granitic outcrop on the north side of Big Windy Creek; the remainder are on the south side of the creek. Spring orifices on both sides seem limited to an elevation of about 6 m above the creek. Any springs in the creek bed are so diluted by the creek that they cannot be recognized.

The springs have deposited buff to white travertine in small terraces on both sides of the creek. The broader terraces are on the north side and are approximately 4 m across and 1 m high. Abundant fragments of granitic rock are mixed with the travertine, and dark-gray deposits within it are probably manganese oxide (table 5). A thin coating of travertine is deposited on granitic boulders in the path of the spring water, but none is deposited where springs issue from the vertical granitic outcrop. Some of the channels in which the water flows over the travertine terraces are lined by green and orange algae.

Temperature of the spring water is about 58°C; pH is about 6.9. Rate of discharge is

TABLE 5.—*Trace element analyses of hot spring deposits on Big Windy Creek, Circle A–1 quadrangle*

[Fe, Mg, Ca, and Ti are reported in percent. Values for all other elements are in parts per million. N indicates element not detected; L indicates element detected in amounts below the limit of determination. Limits for determination for elements with N or L designations are: 5 ppm, cobalt; 20 ppm, niobium; 10 ppm, lead; 5 ppm, scandium; and 10 ppm, yttrium. The following elements were looked for but not found: Ag, As, Au, Bi, Cd, Cu, Hg, Mo, Sb, Sn, Zn, and Th. E. F. Cooley, analyst]

	Fe	Mg	Ca	Ti	Mn	B	Ba	Be	Co	Cr	La	Nb	Ni	Pb	Sc	Sr	V	W	Y	Zr
78AFr3171A	3	0.7	1.5	0.3	300	50	2000	3	10	20	100	L	15	100	70	1000	20	N	20	100
78AFr3171B	.5	.7	>20	.02	>5000	50	2000	70	N	70	50	N	15	N	N	1500	70	200	L	20

difficult to estimate because of the number of springs that flow in many small channels across the travertine and filter through the boulders; however, the flow is small, probably about 8 L/min from each of the larger springs. A mild H_2S odor was noticed throughout the spring area.

Chemical analysis of the water (table 6) shows an unusual composition as compared to the two closest known hot springs, Chena Hot Springs 76 km to the southwest and Circle Hot Springs 27 km to the north (Miller, 1973). The higher carbonate content of the waters of Big Windy Creek hot springs can be related to leaching of the marble in the metamorphic country rock. The high SiO_2 and Na^{+1} concentrations are difficult to explain.

The location of the hot springs within a granitic pluton but close to its edge is consistent with the occurrences of hot springs in central and western Alaska (Miller and others, 1975), which are derived from deeply circulating meteoric water. At present no regional structural feature is known along Big Windy Creek that might be associated with the hot springs. The age of the granitic pluton associated with the Big Windy Creek hot springs is not known, but Miller, Barnes, and Patton (1975) concluded that the distribution of other hot springs in central and western Alaska is independent of

TABLE 6.—*Analysis of water from hot spring on Big Windy Creek, Circle A–1 quadrangle, Alaska*

[Concentrations of HCO_3^-, Ca^{+2}, and SiO_2 are minimum values because facilities were not available in the field for analysis or preservation of the samples. The pH value is a minimum owing to CO_2 loss from the sample. T. S. Presser, analyst. Temperature ∿58°C; pH ∿6.9]

	mg/L		mg/L
Ca^{+2} -------	∿ 42	F^{-1} -------	9.2
Mg^{+2} -------	4.2	SO_4^{-2} -------	79
Na^{+1} -------	440	SiO_2 -------	∿130
K^{+1} -------	21	HCO_3 -------	∿730
Cl^{-1} -------	270	B -------	3

the age, composition, and magmatic events that formed the pluton.

Economic value of the hot springs on Big Windy Creek is limited by their low discharge, small area, and inaccessibility.

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Preliminary results of an augen gneiss study, Big Delta quadrangle

By Cynthia Dusel-Bacon, T. W. Stern, H. L. Foster, and J. L. Bentz

A petrologic and geochronologic study of a large, generally circular body of augen gneiss, approximately 700 km^2 in area, in the southeastern part of the Big Delta quadrangle, Yukon-Tanana Upland, is underway to determine the lithology, age, and origin of its protolith. Because few fossils have been found in the Yukon-Tanana Upland and stratigraphic and contact relations are obscure, this study is needed in order to decipher the geologic and tectonic history of the crystalline rocks of the area. The gneiss we are studying is one of many lithologically similar augen gneisses in the Yukon-Tanana Upland, which may have different origins and ages.

The augen gneiss of this study is composed dominantly of quartz, feldspar, biotite, and white mica with augen, or "eyes," of potassium feldspar that range from 3 to 7 cm in longest dimension. The gneiss is poorly to well foliated and locally has a lineation formed by the subparallel alinement of micas and the longest dimension of the augen. The augen gneiss ranges in metamorphic grade from upper greenschist to middle amphibolite facies and is surrounded by and contains areas of schist, gneiss, marble, and quartzite of similar grade (Weber and others, 1978).

In places, the augen gneiss crops out in tors and monoliths with nearly horizontal foliation, but commonly only coarse, frost-riven blocks and large slabs of rubble occur. Locally, other metamorphic rock types are interlayered with the augen gneiss or crop out adjacent to it, but contact relations with other rocks are generally covered or obscured. Relict sedimentary layering has been considered as an explanation for the interlayering, but the possibility that the layers are tectonic in origin or that the augen gneiss may locally be a sill has also been considered. At one locality, the apparent inclusion of a block of augen-free, more finely crystalline gneiss within the augen gneiss suggests an intrusive relation. Because reconnaissance mapping (Weber and others, 1978) has not determined whether the augen gneiss body is of igneous or sedimentary origin, the present laboratory study was undertaken to resolve this question, among others.

Thin sections and stained and unstained slabs of augen gneiss samples were studied for any relict sedimentary or igneous features that might have survived metamorphism. In thin section, a cataclastic texture was observed in which "eyes" of faintly perthitic potassium feldspar with elongated tails, composed of quartz and feldspar, are contained in a finely crystalline, cataclastic to recrystallized matrix of strained quartz, plagioclase (oligoclase to andesine), and biotite to white mica folia, which are deflected around the "eyes." Zircon, apatite, and opaque minerals are accessory. Myrmekite commonly occurs around the margins of the augen. Fractured augen with offset Carlsbad twins in the feldspar are common.

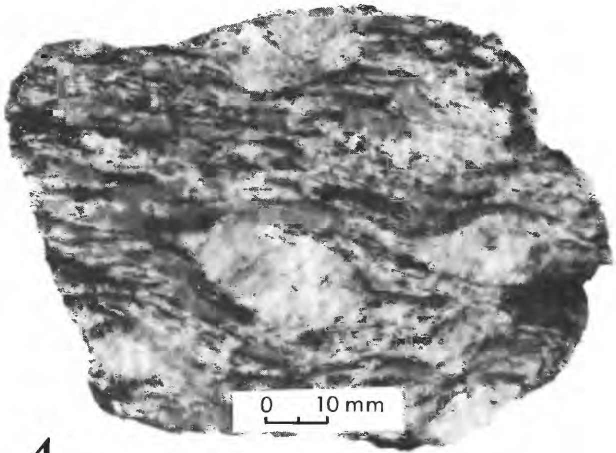
In one thin section, both a monocrystalline and a polycrystalline auge occur. One-half of the polycrystalline auge is a single Carlsbad twin, and the crystals in the other half have straight crystal boundaries and triple-point grain contacts. The occurrence of these two types of augen in a single thin section suggests that a single large feldspar crystal had begun to recrystallize into a polycrystalline aggregate, not that a large crystal had grown from many, originally small ones.

A dominatly cataclastic texture is apparent in most slabs of the augen gneiss (fig. 23*A*). Staining of slabs for potassium reveals that almost all of the potassium feldspar of the rock occurs in the augen. In a slab from a sample locality in which the augen are particularly idiomorphic, concentric zoning of biotite and plagioclase inclusions was observed (fig. 23*B*). This texture, commonly found in igneous megacrysts (Kerrick, 1969), strongly suggests that the augen are porphyroclasts from a porphyritic igenous parent, rather than prophyroblasts that grew during metamorphism. Although many of the larger augen from this locality are idiomorphic, most of the smaller crystals have the typical smeared-out auge shape. Perhaps the size and orientation of the crystals determine their shape and the degree of preservation of relict textures.

Examination of the morphology of zircons that were separated from a sample used for radiometric dating has indicated that there is a mixed population with many different shapes and sizes. Most of the zircons in the sample are subhedral to euhedral rather than rounded. Some crystals have rounded, inclusion-rich cores, with subhedral to euhedral, inclusion-poor overgrowths with slightly rounded corners. A preliminary microprobe analysis of zircon inclusions tentatively identified two very small Al_2SiO_5 inclusions. If some of the zircons indeed have inclusions of this composition, the protolith of the gneiss contains material from a source that has undergone a weathering cycle.

Uranium-thorium-lead dating of zircons from the augen gneiss is currently underway, and data are available for one sample. This first sample yielded discordant ages ($^{206}Pb/^{238}U$: 317.3 m.y.; $^{207}Pb/^{235}U$: 341.7 m.y.; $^{208}Pb/^{232}Th$: 332.4 m.y.; $^{207}Pb/^{206}Pb$: 511.3 m.y.), which suggest a late Precambrian age for the zircons. Whether these data reflect the age of inherited zircon or the age of crystallization of the augen gneiss remains to be determined.

The preliminary observations described above suggest that the augen gneiss may have developed from metamorphism and cataclasis of a porphyritic granitic rock. The rounded cores of some zircons and the Al_2SiO_5 inclusions further suggest that the granitic protolith may have been formed by anatexis of sedimentary rocks. It may be that the tentative Precambrian zircon age reflects the age of detritus that could have been partially fused to form the postulated granitic magma. Further uranium-thorium-lead dating of zircons from the augen gneiss and other related metamorphic rocks should either substantiate this hypothesis or suggest an alternative one.



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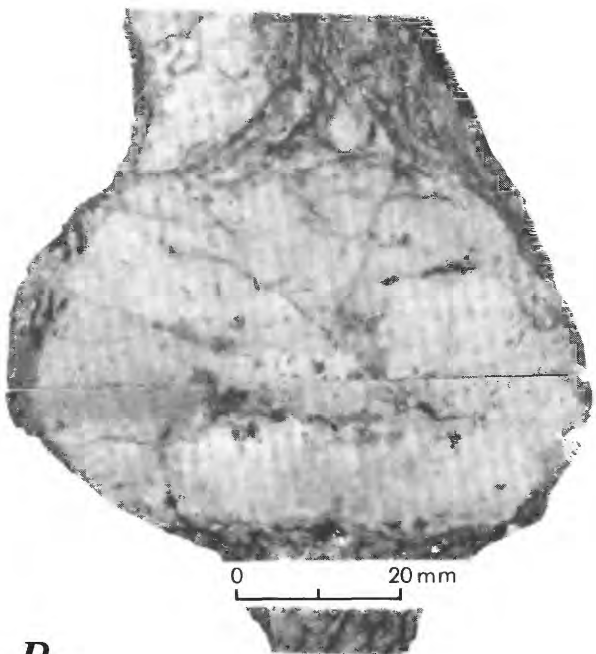

B

FIGURE 23.—Slabs of augen gneiss from Big Delta quadrangle. *A*, Unstained slab showing typical flaser structure. *B*, Stained slab showing concentricity of inclusions parallel to margins of idiomorphic potassium feldspar auge. Gray tabular inclusions are plagioclase; black flakes, biotite. Line through auge is edge of section cut perpendicular to face shown; perpendicular section shows same zonation of inclusions.

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Geohydrology of the Delta-Clearwater area
By D. E. Wilcox

An hypothesis developed from a hydrological model of the Delta-Clearwater area indicates that the aquifer transmitting water to the spring-fed Clearwater Creek-Clearwater Lake system is recharged, at least in part, by seepage losses from the Tanana River to the east of the springs. The hydraulic gradient west of the Tanana River 29 km above the mouth of the Gerstle River sloped in a northwesterly direction at about .85 m/km on October 15, 1978. The water level in a well approximately 30 m west of the Tanana River was 9.02 m below the water surface in the river on that date. These findings indicate that the Tanana River in this area is perched and influent to the aquifer during at least part of the year.

Geohydrology of Fairbanks North Star Borough
By Andrea Krumhardt

The geohydrologic study of the Fairbanks North Star Borough, Alaska, is a continuing program designed to provide basic hydrologic data for land-use planning. Since its initiation in 1975, the program has expanded to the outlying areas. Most recently canvassed was the Chena Ridge area southwest of Fairbanks.

Although some homeowners there have experienced reduced yield in their wells, the majority reported no noticeable changes. Well water in the Chena Ridge area has total arsenic concentrations ranging from 0 to 6 μg/L, well under the U.S. Public Health Service (USPHS) recommended limit of 50 μg/L.

Nitrate concentrations exceeding the USPHS recommended limit of 10 μg/L were found in samples from two wells. The source and extent of nitrate in ground water around Fairbanks are still relatively unknown.

Water levels in a deep observation well on the ridge directly north of Fairbanks continue to decline at a rate of about 1.5 m per year. Whether this drop is due to decrease in precipitation or to an increase in the number of wells tapping the aquifer has not been determined.

WEST-CENTRAL ALASKA

Two upper Paleozoic sedimentary rock units identified in southwestern part of the Ruby quadrangle
By Robert M. Chapman and William W. Patton, Jr.

Two sedimentary rock units in the southwestern part of the Ruby quadrangle (fig. 24), one consisting of chert with some slaty argillite, and the other composed of graywacke sandstone, conglomerate, and mudstone, have been differentiated and dated as a result of recent reconnaissance mapping. Late Paleozoic ages have been determined for these units that were formerly thought to be of Mesozoic (?) age (Mertie and Harrington, 1924, p. 22–24). Bedrock is largely concealed in this area by a widespread cover of colluvium, silt, and vegetation, and only limited bedrock data and samples can be obtained from discontinuous hilltop rubble and rare, isolated outcrops. It was not possible to observe details of lithologic succession and structure or to determine the nature of the contact between the two units. Contacts between these units and the older carbonate and low-grade metamorphic rock units, which are near Poorman, along the Sulatna River, and just outside of the map area northeast of Lost River (fig. 24), are covered and their nature is unknown.

The unit of medium-dark- to dark-gray, thin-banded, bedded, radiolarian-bearing chert, weathered to various shades of gray, greenish gray, and reddish brown, with thin interbeds of slaty argillite, lies between Timber Creek and the head of May Creek. The graywacke unit has been mapped in two places; one in the headwaters of Glacier Creek just south of the chert and argillite unit, and the other on a hill about 25 km northeast between Lost River and the headwaters of Bonanza Creek. This unit includes (a) fine- to medium-grained, medium-gray to dark-greenish-gray graywacke, weathered to various shades of olive to brownish gray and moderate to dark yellowish brown, calcareous in

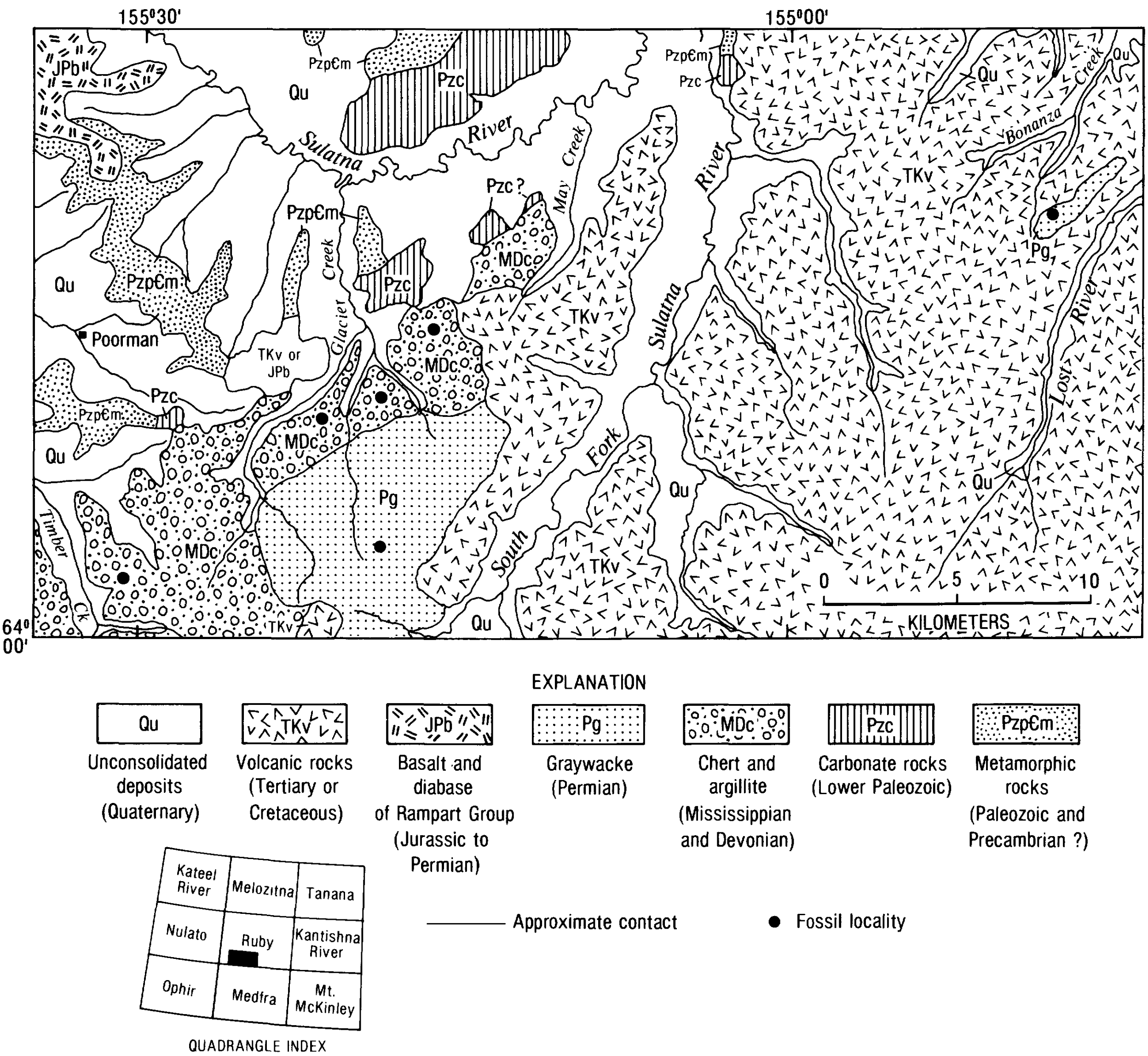

FIGURE 24.—Generalized geologic map of southwestern part of Ruby quadrangle.

part, and containing some dark-gray shale fragments; (b) grit to small-pebble graywacke conglomerate with clasts of andesitic and basaltic rock, shale, chert, quartzite, and a few schistose rocks in a sand and mud matrix; and (c) mudstone and shale, greenish-gray to medium-dark gray, weathered to moderate and dark yellowish brown to dark yellowish orange. Probable Permian microfossils together with bryozoan and echinoderm fragments were found in graywacke at the Lost River locality, and shale from this site contained pollen, which was nondiagnostic (R. A. Scott, oral. commun., 1978). The rocks in the headwaters of Glacier Creek are lithologically similar to those near Lost River, but no fossil material, other than an imprint of a possible ammonite fragment that "affords no basis for any definite age assignment" (Mertie and Harrington, 1924, p. 24), has been found.

Mertie and Harrington included all of the above rocks in one unit described as "chert, argillite, and some interbedded rhyolitic tuff (pl. 3)." They mapped this unit both in the Ruby quadrangle and in a discontinuous belt that extends about 160 km southwestward to Mount Hurst in the southeastern part of the

Ophir quadrangle. On the basis of field evidence, they assigned these rocks "provisionally to the Mesozoic, though they may prove eventually to be of Carboniferous age" (p. 24). Mertie and Harrington suggested that possibly the "sandy and gritty material is not an integral part of the chert-argillite series" (p. 23) and also stated that, although soda rhyolite flows and tuffs are intimately associated with the sedimentary members of the chert-argillite series and appear to be interbedded, the "available evidence as to stratigraphic relations is not entirely conclusive" (p. 23).

Our differentiation of the graywacke unit, on the basis of field relations, is supported by identification of nodosinellids, *Tetrataxis*, and bryozoan and echinoderm debris by A. K. Armstrong (written commun., 1976) and R. C. Douglass and J. T. Dutro, Jr. (written commun., 1978), their agreement on probable Permian age for this faunal assemblage, the lithologic similarity between this unit and Permian clastic rocks in the Livengood quadrangle (Chapman and others, 1971), and the reservations of Mertie and Harrington about grouping the sandy and cherty rocks. Adjacent to and east of the South Fork of Sulatna River, the graywacke and chert and argillite units are unconformably overlain and largely concealed by Tertiary or Cretaceous extrusive rhyolitic and basaltic rocks; the graywacke unit that crops out near Lost River apparently is an inlier surrounded by these volcanic rocks. Provisionally, the graywacke unit is assigned a Permian age. This unit probably is correlative with similar clastic rocks of the Permian (?) Rampart Group elsewhere in central Alaska. Some graywacke-unit rocks may be present, but as yet unidentified, in the Rampart Group to the northeast, north, and northwest in the Ruby and Nulato quadrangles. Graywacke-unit rocks have not been found in the adjacent part of the Medfra quadrangle to the south.

Radiolarians in four chert samples from the chert and argillite unit have been identified by B. K. Holdsworth and D. L. Jones (written commun., 1978) as *Cyrtisphaeractenium* fauna apparently with *Holoeciscus* of very latest Famennian (Devonian) age (two samples), *Paronaella* fauna probably of Mississippian age (one sample), and *Paronaella* with Neohagiastrids of Late(?) Mississippian age (one sample). Additional sampling and field study in the Ruby quadrangle are needed better to define the fauna and lithology. This unit extends southwestward into the adjacent Medfra quadrangle in a 15-km-wide belt of varicolored bedded chert that includes a few thin lenticular bodies of limestone. Radiolarians, conodonts, and foraminifers of Mississippian age were found at eight widely scattered localities within this belt, which is part of the Innoko terrane (Patton, 1978). Radiolarians of Mississippian age (B. K. Holdsworth, written commun., 1978) are present in chert at the head of McLean Creek, about 60 km southwest in the Ophir quadrangle. An age range of very latest Devonian to Late(?) Mississippian is provisionally assigned to the chert and argillite unit in the Ruby quadrangle, and a correlation with the above-mentioned cherts in the Medfra and Ophir quadrangles is suggested.

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Age of the metamorphic complex in the northern Kuskokwim Mountains, west-central Alaska

By William W. Patton, Jr., and J. Thomas Dutro, Jr.

New evidence from the northern part of the Medfra quadrangle establishes the age of the metamorphic complex in the northern Kuskokwim Mountains as definitely pre-Permian and probably pre-Ordovician. On a tributary of Meadow Creek in the north-central part of the quadrangle, pelitic schist and greenstone of the metamorphic complex are overlain by a massive basal conglomerate of Permian age (fig. 25, sec. C). The conglomerate contains large angular blocks of the metamorphic rocks set in a sandy quartz-carbonate matrix that carries an abundant early Late Permian brachiopod fauna. The presence of these large clasts of metamorphic rocks in the Permian strata demonstrates clearly that the age of metamorphism is pre-Permian

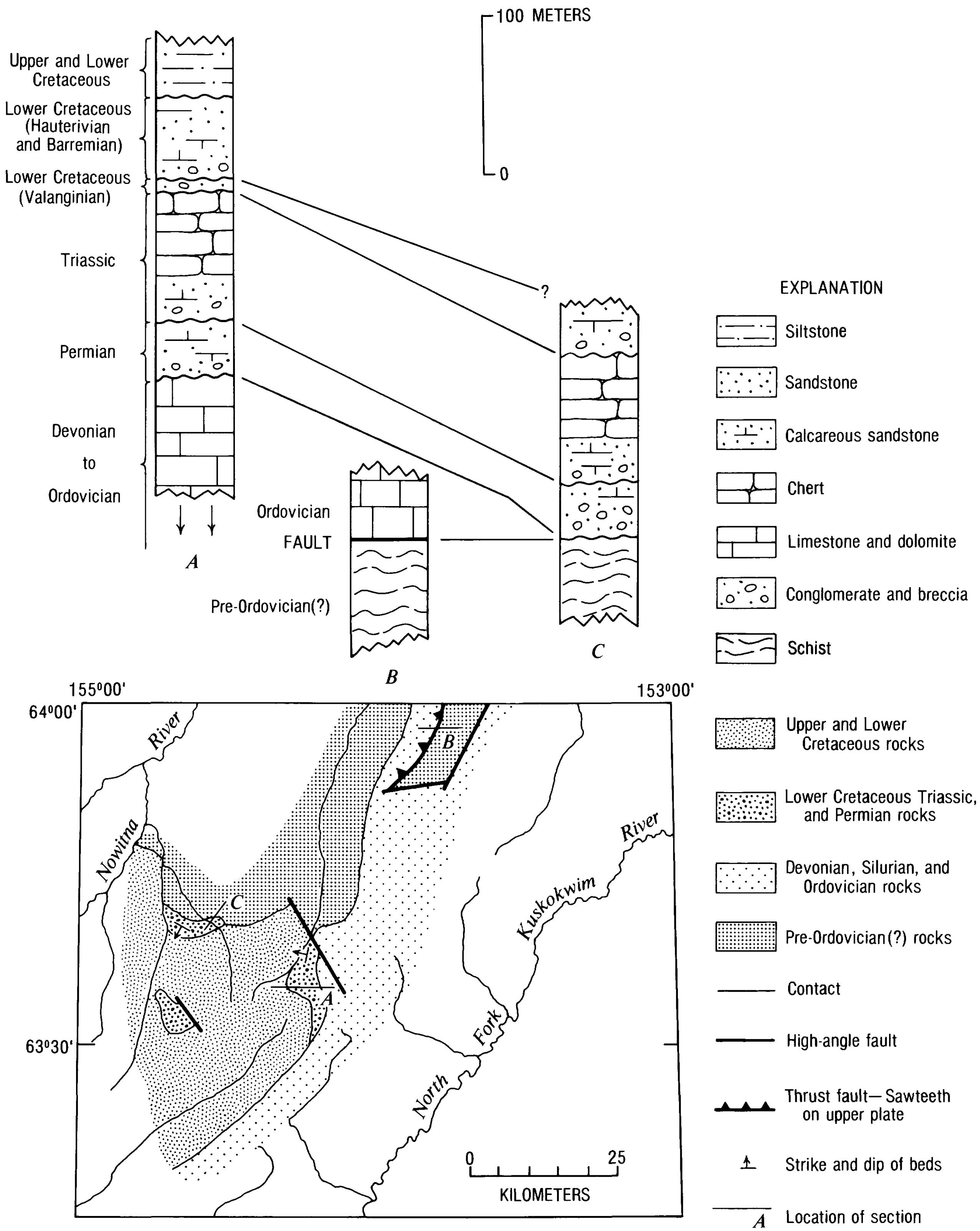

FIGURE 25.—Geologic map and stratigraphic sections, northern Kuskokwim Mountains.

and rules out the possibility that large-scale thrust faulting has occurred between the Permian beds and the metamorphic complex. A pre-Ordovician age for the metamorphic complex is strongly suggested by the fact that the Permian strata, 20 km east of Meadow Creek, disconformably overlie an unmetamorphosed carbonate rock sequence of earliest Ordovician to Late Devonian age (fig. 25, sec. A). Conodont samples collected at widely scattered localities in the carbonate terrane show by their color alteration index (Epstein and others, 1977; J. E. Repetski, and J. E. Repetski and A. G. Harris, written communs., 1977–1979) that the lower Paleozoic rocks have been subjected to temperatures no greater than 300°C—well below the temperature required for greenschist-facies metamorphism.

The metamorphic complex originally was assigned a pre-Ordovician age by H. M. Eakin (1916), on the basis of observations in the Telsitna River area where Ordovician carbonate rocks structurally overlie the metamorphic complex (fig. 25, sec. B). Eakin regarded the contact as an angular unconformity. However, our reexamination showed that the contact is, in fact, a thrust fault and that a pre-Ordovician age, while possible, cannot be proven at this locality (Patton, 1977).

In an accompanying report, Silberman and others (1979) present preliminary results of potassium-argon dating which suggest a Precambrian radiometric age for the metamorphic complex.

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Potassium-argon age of granitic and volcanic rocks from the Ruby, Medfra, and adjacent quadrangles, west-central Alaska

By M. L. Silberman, E. J. Moll, R. M. Chapman, W. W. Patton, Jr., and C. L. Connor

The geochronological investigation of granitic plutons and volcanic rocks in the Ruby, Medfra, and adjacent quadrangles covers parts of two distinct geologic-tectonic provinces (fig. 26). The first, the Yukon-Koyukuk province, found only in the northwest corner of the Melozitna quadrangle, consists of a wedge-shaped basin filled with volcanic rocks and volcanogenic sedimentary rocks of Early and early Late Cretaceous age, which are overlain by Cretaceous and early Tertiary(?) volcanic rocks. The second, the Ruby province, consists of a broad belt of Precambrian and possible Paleozoic metamorphic rocks, lower Paleozoic shelf-carbonate rocks, and upper Paleozoic and Mesozoic terrigenous sedimentary and island-arc oceanic rocks (not shown on map). This province extends southwesterly along the southeast edge of the Yukon-Koyukuk province from the southern Brooks Range to the Yukon-Kuskokwim delta and is bounded on the southeast by the Yukon-Tanana metamorphic complex. The island-arc oceanic rocks appear to consist of remnants of allochthonous sheets of mafic and ultramafic rocks, volcaniclastic sedimentary rocks, and chert, which were emplaced between Jurassic and Early Cretaceous time (Patton and others, 1977). The rocks of both provinces are intruded by Cretaceous granitic plutons and are locally overlain by Cretaceous and Tertiary volcanic rocks (Patton, 1973). The Kaltag fault, which cuts across the Ruby and Yukon-Koyukuk provinces (fig. 26), has 130 to 150 km right-lateral offset (Patton, 1973).

Twenty-two mineral and whole-rock potassium-argon ages were determined from 19 samples of granitic and volcanic rocks (table 7, and fig. 26). Determinations of the ages of the metamorphic rocks by similar methods are reported by Silberman and others (1979).

The granitic plutons (table 7) are divided into two age groups: a younger group that ranges

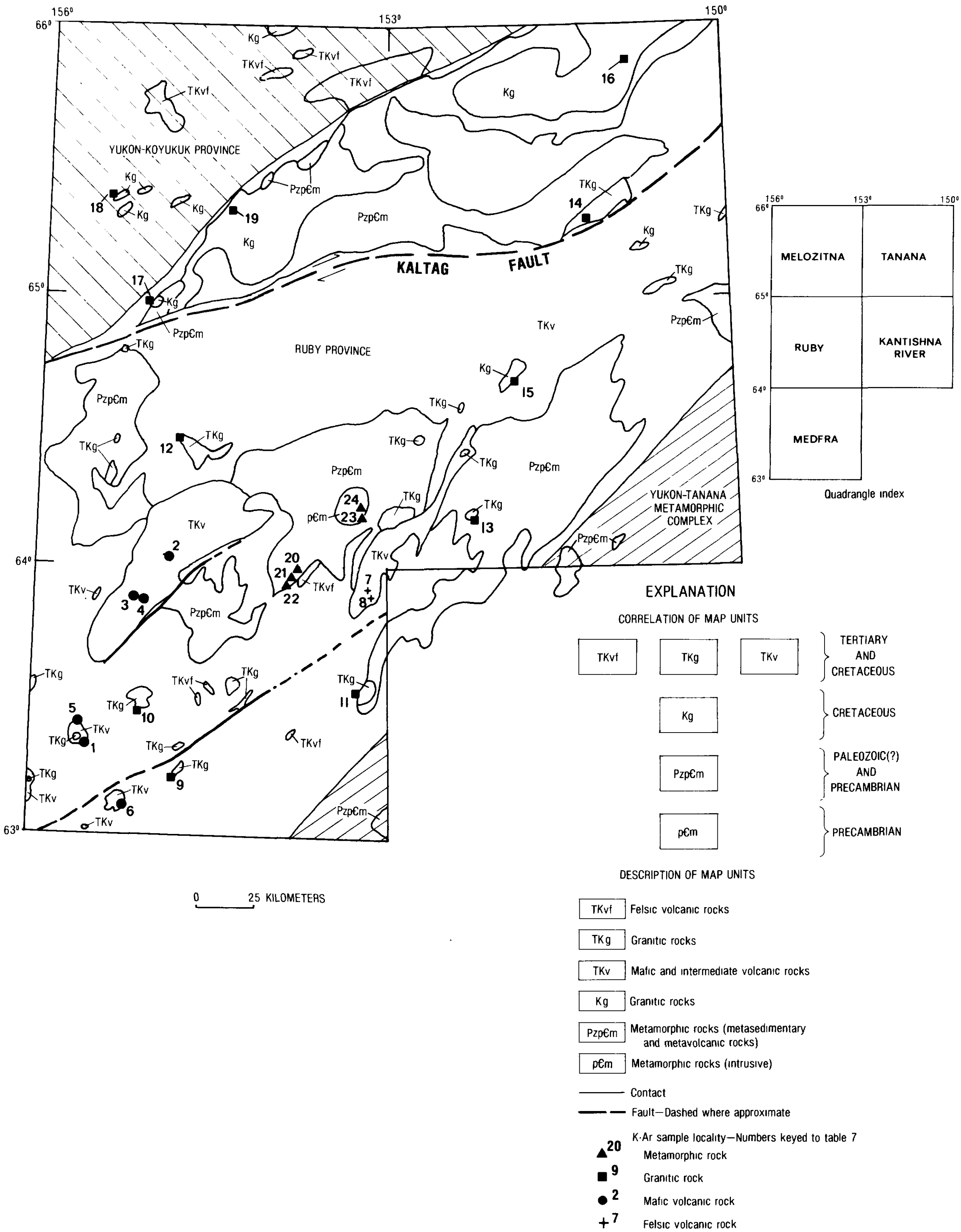

FIGURE 26.—Generalized distribution of Precambrian and Paleozoic(?) metamorphic rocks, Cretaceous and Tertiary granitic and volcanic rocks, and major structural features in Medfra, Ruby, and adjacent quadrangles. (Geology modified from Eberlein and others, 1977).

TABLE 7.—*Potassium-argon ages of igneous and metamorphic rocks of west-central Alaska*

Sample No.	Rock type	Mineral	Age (m.y.)	Quadrangle
		Mafic and intermediate volcanic rocks		
1	Basalt (altered)	Whole rock	59.5 ± 1.8	Medfra
2	Basalt	Whole rock	62.9 ± 2.8	Ruby
3	Andesite	Whole rock	63.8 ± 2.7	Medfra
4	Andesite	Whole rock	64.2 ± 2.8	Medfra
5	Andesite	Biotite	69.8 ± 2.6	Medfra
6	Basalt (altered)	Whole rock	68.9 ± 2.8	Medfra
		Felsic volcanic rocks		
7	Rhyolite	Whole rock	69.9 ± 2.7	Medfra
8	Rhyolite	Whole rock	71.0 ± 2.8	Medfra
		Cretaceous-Tertiary granitic rocks		
[1] 9	Quartz monzonite	Biotite	69 ± 2	Medfra
10	Quartz monzonite	Biotite	63.4 ± 2.5	Medfra
11	Quartz monzonite	Biotite	70.5 ± 2.8	Medfra
12	Quartz monzonite	Biotite	69.6 ± 2.1	Ruby
13	Quartz monzonite	Biotite	64.2 ± 1.9	Kantishna River
14	Quartz monzonite	Biotite	61.8 ± 2.5	Tanana
		Mesozoic granitic rocks		
15	Granodiorite	Biotite	91.3 ± 2.7	Kantishna River
	Quartz monzonite	Hornblende	92.5 ± 2.8	Kantishna River
16	Quartz monzonite	Biotite	104 ± 3	Tanana
17	Quartz monzonite	Biotite	110 ± 3	Ruby
		Muscovite	110 ± 3	Ruby
[2] 18	Granodiorite	Biotite	82.3 ± 3	Melozitna
		Hornblende	89.0 ± 3	Melozitna
[2] 19	Quartz monzonite	Biotite	111 ± 3	Melozitna
		Precambrian rocks		
20	Mica schist	Muscovite	296 ± 10	Medfra
21	Mica schist	Muscovite	514 ± 18	Medfra
22	Mica schist	Muscovite	411 ± 15	Medfra
23	Mylonite schist	Muscovite	663 ± 20	Ruby
24	Sheared diorite	Biotite	921 ± 25	Ruby

[1] Reed and Miller (1971)

[2] Patton and others (1978)

from approximately 60 to 70 m.y. old and an older group that ranges from 80 to 110 m.y. old. The younger plutons are small bodies, generally less than 100 km^2, and are composed of quartz-monzonite or granodiorite. They intrude Precambrian metamorphic rocks, Paleozoic carbonate rocks, Mesozoic clastic rocks, and Late Cretaceous and early Tertiary mafic volcanic rocks and are found mostly in the southern part of the area.

The older group of plutons are also quartz-monzonite and granodiorite but range in outcrop area from a few to several hundred square kilometers. These plutons intrude Paleozoic(?) and (or) Precambrian and Paleozoic(?) metamorphic rocks and Mesozoic sedimentary and volcanic rocks. They are concentrated in the northern part of the area, and all but one pluton (sample 15, fig. 26 and table 7) lie north of the Kaltag fault. Plutons of similar age to this 80- to 110-m.y.-old group occur in the Hogatza plutonic belt in the northern part of the Yukon-Koyukuk province (Patton, 1973).

On the basis of a few initial chemical analyses, the plutonic rocks follow calc-alkaline trends (R. M. Chapman and M. L. Silberman, unpub. data, 1978). That the plutons were emplaced in Cretaceous and early Tertiary time, apparently without strong regional metamorphism, is shown by two lines of evidence: 1) the Paleozoic and Mesozoic country rocks have not undergone regional metamorphism, and 2) micas in the Precambrian schists have not been totally reset by diffusional loss of argon, as would be expected in a major regional metamorphic event (Silberman and others, 1979).

The younger plutons in the Medfra quadrangle are closely associated in time with both felsic and mafic volcanic rocks. All the potassium-argon data on volcanic rocks are from the Medfra quadrangle. Two groups of calc-alkalic volcanic rocks are exposed in the Medfra quadrangle (fig. 26). The first group consists of Cretaceous and Tertiary felsic volcanic rocks and includes a narrow northeast-trending belt of rhyolite and dacite lava flows and domes exposed in the northeast part of the quadrangle and numerous hypabyssal dikes, sills, and domes scattered throughout the area. Two samples from the northeastern belt give whole-rock ages of 70 and 71 m.y. (table 7). Felsic volcanic rocks similar to this suite in the Medfra quadrangle occur in the northern part of the Melozitna quadrangle but have not been dated.

The second group of volcanic rocks consists dominantly of pyroxene andesite and biotite-hornblende andesite and basalt flows and intrusions found mostly in the west half of the Medfra quadrangle. A large northwest-trending belt of these rocks in the northern Medfra and southern Ruby quadrangles has yielded three potassium-argon whole-rock ages of 63 to 64 m.y. (table 7). Three isolated andesitic to basaltic complexes that intrude and overlie Cretaceous sedimentary rocks in the southwest part of the Medfra quadrangle have been intruded by small granitic bodies. The granitic bodies have not yet been dated, but three potassium-argon dates of the andesite and basalt are 60, 69, and 70 m.y. However, the youngest sample was hydrothermally altered.

All available potassium-argon dates on the granitic and volcanic rocks from the southern part of the area are in the 60- to 70-m.y.-old range. The overlapping ages and calc-alkalic composition suggest that the intrusive rocks may represent deeper erosion levels of the same magmatic event that produced the volcanic rocks. In the southwest corner of the Medfra quadrangle, the small granitic plutons that intrude the cores of mafic and intermediate volcanic piles may possibly be late-stage differentiates of magmas that originally produced the mafic volcanic rocks.

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Precambrian age of metamorphic rocks from the Ruby province, Medfra and Ruby quadrangles—preliminary evidence from radiometric age data

By M. L. Silberman, E. J. Moll, W. W. Patton, Jr., R. M. Chapman, and C. L. Connor

The Ruby province contains extensive exposures of metamorphic rocks of Precambrian and Paleozoic(?) age (fig. 26). This discussion of five potassium-argon ages from some of the schists and metagranitic rocks of the province is a preliminary result of an isotopic study of the age and metamorphic history of the metamorphic rocks in west-central Alaska.

Metamorphic rocks in the Ruby province

include schist, metaquartzite, marble, phyllite, mafic and felsic metavolcanic rocks, and gneissic and schistose plutonic rocks (Patton and others, 1978; Chapman and Patton, 1978). The generalized distribution of the metamorphic rocks is shown in figure 26, along with Cretaceous and Tertiary granitic and volcanic rocks that intrude and overlie them. Lower Paleozoic shelf carbonate rocks and upper Paleozoic and Mesozoic terrigenous sedimentary and mafic volcanic and volcaniclastic rocks overlie the metamorphic complex.

The oldest potassium-argon age (table 7, sample 24) comes from a sheared metamorphosed quartz diorite that intrudes quartz-mica schist in the southeastern part of the Ruby quadrangle (fig. 26). The intrusive rock is porphyritic and contains biotite phenocrysts as large as 1 cm and numerous microveinlets of quartz. The biotite gives an age of 921 m.y. Muscovite from a recrystallized mylonite along the border of the pluton gives an age of 663 m.y. The fact that the muscovite penetrates quartz veinlets and fills gash fractures in the mylonite suggests that deformation and recrystallization occurred at or before 663 m.y. ago.

In the Medfra quadrangle (fig. 26), stratigraphic evidence indicates that the metamorphic rocks are pre-Ordovician in age (Patton and Dutro, 1979). However, three samples of fine-grained quartz-muscovite-chlorite schist from the north edge of the quadrangle yield muscovite and muscovite-chlorite ages of 296, 411, and 514 m.y. (table 7) (Cambrian to Pennsylvanian). At least two of the samples appear to have lost argon, and, therefore, the potassium-argon ages can only be regarded as minimum ages. Because these samples of schist were collected near outcrops of Cretaceous and Tertiary felsic volcanic rocks (fig. 26), the fine-grained micas may have lost argon from thermal effects related to this igneous activity. However, argon loss cannot be correlated with distance to present exposures of rhyolite. The ages appear to depend chiefly on grain size for, although all the schist samples are fine grained, the sample with the coarsest grained mica yields the oldest age (514 m.y.). The schists that were sampled along the northern border of the Medfra quadrangle are similar to those nearby in the southeastern part of the Ruby quadrangle, which are intruded by the sheared diorite. Thus, stratigraphic and radiometric age data, although not diagnostic enough to specify either the age of the metamorphic basement complex or its metamorphic history, demonstrate that at least some of the metamorphic rocks in the Ruby-Medfra area are as old as Precambrian.

The Ruby province is offset right laterally as much as 130–150 km along the Kaltag fault (Patton, 1973; fig. 26). Although all our data are from samples collected south of the fault, metamorphic rocks that are lithologically similar and probably of equivalent age also occur north of the fault (Patton, 1973; Patton and others, 1978).

Late Cretaceous and early Tertiary volcanism and plutonism in the area (Silberman and others, 1979) do not appear to have strongly affected the potassium-argon ages of the metamorphic complex. If strong regional metamorphism had accompanied this igneous activity, we would expect that at least the fine-grained mica from the schists would have been completely reset from loss of argon, as occurred during the last stage of metamorphism of similar metamorphic rocks in the southern Brooks Range (Turner and others, 1978). Rubidium-strontium and uranium-lead isotopic age studies will be initiated in 1979 better to define the age and metamorphic history of the metamorphic rocks in this region.

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Uranium-thorium investigations of the Darby pluton, Seward Peninsula, Alaska

By Bruce R. Johnson, Thomas P. Miller, and Susan Karl

The Darby pluton is an elongate, granitic body approximately 80 km long and 3 to 8 km wide in the eastern Darby Mountains (fig. 27). The pluton has been considered a favorable area for exploration because uranium and thorium content is two to three times reported averages for granitic rocks (Miller and Bunker, 1976). Miller and Bunker also noted apparent zoning of the pluton from north to south but did not have sufficient data to pinpoint areas of potentially high concentration of radioactive elements.

During the summer of 1977 several east-west traverses (fig. 27) were made across the northern part of the pluton to look for mineralogic or radioelement zonation. Scintillometer readings were made at each sampling location, and large (10–20 kg) samples were collected of each lithology present.

The Darby pluton is composed of coarse-grained, porphyritic granite commonly containing aplitic leucogranite dikes. The porphyritic granite consists primarily of large, tabular, pink potassium feldspar phenocrysts (up to 35 mm long) in a medium- to coarse-grained groundmass of feldspar and quartz. The granite contains about 6 percent mafic minerals, primarily biotite and occasional hornblende. Accessory minerals include magnetite, allanite, sphene, apatite, zircon, and muscovite. Most samples examined showed little alteration, although slight sericitization of feldspars is common, and occasional samples show chloritization of biotite.

The aplitic dikes differ from the porphyritic granite primarily in grain size and total mafic content. The aplites consist of intergrowths of subequal amounts of quartz and potassium feldspar and slightly less plagioclase. Maximum grain size averages about 5 mm, and the mafic mineral content averages less than 2 percent.

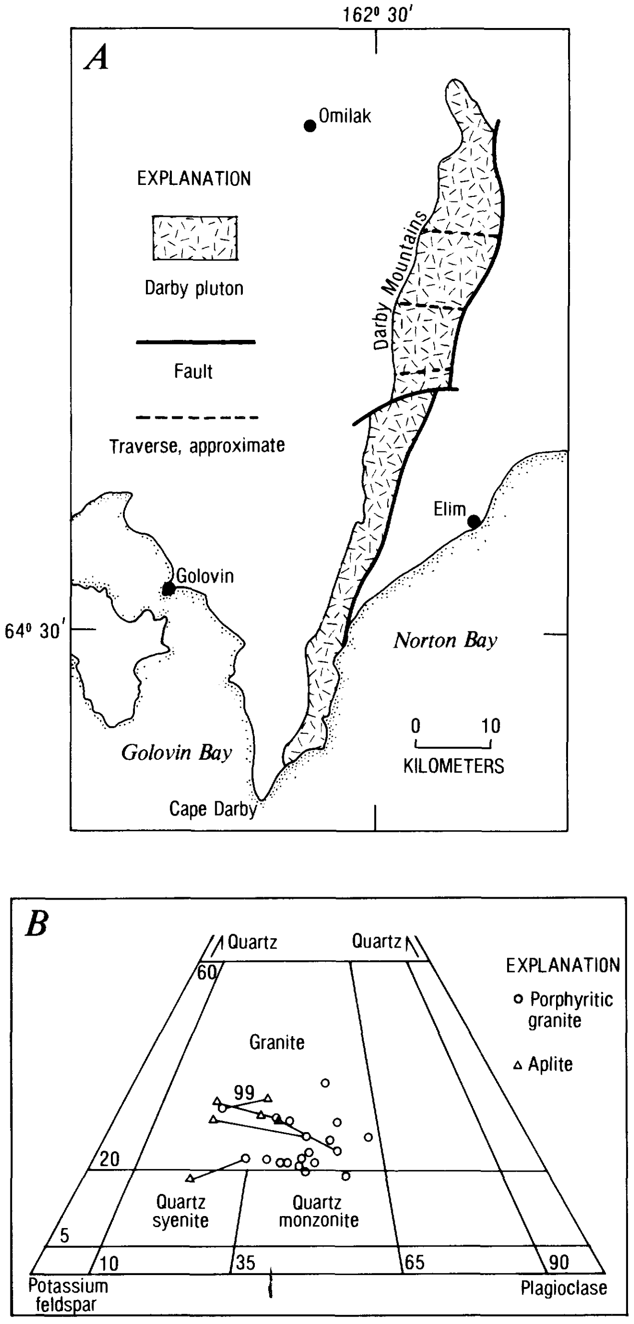

FIGURE 27.—Darby pluton, Seward Peninsula. *A*, Map showing location of traverses in Darby pluton, *B*, Ternary diagram showing modal compositions of coarse-grained porphyritic granite and aplite dikes (see table 8). Tielines connect aplite and granite samples from same locality; gg indicates only aplite with higher plagioclase and mafic mineral content than associated granite. Composition subdivisions after Streckeisen (1973).

Accessory minerals in the aplites are the same as those in the porphyritic granite with the exception of hornblende, which was not found in the aplitic dike samples.

Modal analyses were completed for 19 samples of porphyritic granite and 6 samples from aplitic dikes. Feldspar, quartz, and mafic-mineral contents were determined by point counting a minimum of 1,000 points on polished slabs that had been stained for potassium feldspar. The modal data are plotted on a quartz-potassium feldspar-plagioclase diagram (fig. 27) and are summarized in table 8. Tielines in figure 27 connect compositions of aplite samples with the compositions of granite samples from the same locality. Aplite dikes have lower plagioclase and mafic mineral content than the adjacent granite and show a corresponding increase in quartz and potassium feldspar. The one exception (gg on fig. 27) is an aplite contained in a graphic granite that is itself quite low in plagioclase and mafic minerals.

Also summarized in the table are the results of gamma-ray spectrometric and delayed-neutron analyses of the same samples. Gamma-ray technique (Bunker and Bush, 1966) determines uranium content indirectly by measuring the amount of radium and calculating radium-equivalent uranium (RaeU). Radium-equivalent uranium is equal to actual uranium content if the uranium is in equilibrium with its radium daughter products. Delayed-neutron analysis (Millard, 1976) measures the uranium and thorium content of the sample directly. In a study of various uranium and thorium analytical techniques, Stuckless and others (1977) found most RaeU values to be lower than the actual

TABLE 8.—*Summary of modal, gamma-ray, and delayed-neutron analyses of samples from the northern Darby pluton*

[Feldspar, quartz, and mafic mineral analyses in percent; others in parts per million. G, gamma-ray spectrometry; D, delayed-neutron analysis; RaeU, radium-equivalent uranium. Gamma-ray spectrometer analyses by C. M. Bunker and C. A. Bush; delayed-neutron determinations by H. T. Millard, Jr., C. McFee, and C. Bliss]

	Porphyritic granite (19)			Aplite (6)		
	Max.	Min.	Mean	Max.	Min.	Mean
K-feldspar	51	22	37.9	62	40	48.1
Plagioclase	43	18	33.1	28	16	21.6
Quartz	35	18	23.4	33	18	28.5
Mafic minerals	22	1	5.6	3	1	1.7
G-RaeU	24	6	11.5	24	8	14.8
G-Th	124	23	57.9	68	43	57.9
D-U	18	7	10.4	31	8	15.8
D-Th	108	26	58.4	73	39	60.1

uranium values by 15–20 percent. They attribute this lack of agreement to the possible presence of labile uranium that is not yet in equilibrium with its radium daughter products. The close agreement between RaeU and uranium values from delayed-neutron analysis in this study may be an indication that the uranium is tightly bound up in the rock and has not been redistributed since crystallization of the magma. The mean content of uranium measured by both techniques is higher in the aplite dikes than in the porphyritic granite. This difference may indicate concentration of the uranium in the latest stages of crystallization of the magma, although the aplite sample population is small and may not be statistically significant. Brief examination of fission-track maps indicates that uranium is concentrated primarily in the refractory minerals zircon, allanite, and sphene. Lower concentrations of uranium are found along grain boundaries, fractures, and cleavage traces; this portion of the uranium is probably more susceptible to leaching and redistribution.

The most striking feature of the Darby pluton is its homogeneity. The parts of the pluton sampled in this and earlier studies (Miller and Grybeck, 1973; Miller and Bunker, 1976) are homogeneous both in their mineralogy and in their radioactive element chemistry. Although the apparent absence of uranium redistribution in the pluton is not encouraging, much of the pluton remains unknown and areas of economic concentration of radioactive elements may be present. Exploration targets suggested by this study include areas of late magmatic activity (aplites and pegmatites) and areas of suspected hydrothermal activity, particularly near the north end of the pluton where gross radioactivity is highest (Miller and Bunker, 1976).

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Quartzofeldspathic, mafic, and ultramafic granulites identified in the Kigluaik Mountains, Seward Peninsula, Alaska

By M. L. Throckmorton and C. L. Hummel

The Kigluaik Mountains on Seward Peninsula have formed from an uplifted block of rocks called the Kigluaik uplift; collectively, the rocks comprise the Kigluaik metamorphic complex. The greatest part of the complex consists of high-grade, regionally metamorphosed, sedimentary rocks; the remainder includes orthogneiss bodies, dikes and sills of quartz monzonite, basalt, and pegmatite, and meta-ultramafic rocks. The metasedimentary rocks are quartzite, quartz-feldspar-biotite schist and gneiss, calc-silicate rocks, and marble, all intimately interlayered and gradational in composition. Although the metasedimentary types occur throughout the complex, more quartzose metasedimentary rocks predominate along the south side of the uplift, and calcareous varieties are more abundant toward the north. Several large orthogneiss sills are conformably interlayered with the metasedimentary rocks. Meta-ultramafic rocks, first identified in 1974, were found only at the base of the east face of Mount Osborn; neither their abundance nor distribution was established at the time.

The Kigluiak uplift is bounded on the north and south by high-angle, normal faults. Within the uplift, the layered metamorphic rocks are in the form of a broad, east-trending anticline, named the Kigluaik arch (Hummel, 1962). The axis of the Kigluaik arch lies just north of Mount

Osborn and plunges east and west from there (fig. 28). Across the north boundary fault, the Kigluaik uplift is flanked by surficial deposits of glacial and alluvial origin; some of these deposits have been faulted and thus demonstrate recent movement on the fault. Along the south boundary fault, high-grade rocks of the Kigluaik metamorphic complex on the north are juxtaposed against greenschist-facies metamorphic rocks that form the bedrock throughout the region south of the mountains. Petrographic study of the high-grade metamorphic rocks indicates a gradation from amphibolite facies at the south boundary fault to granulite facies at the base of Mount Osborn in the core of the Kigluaik arch.

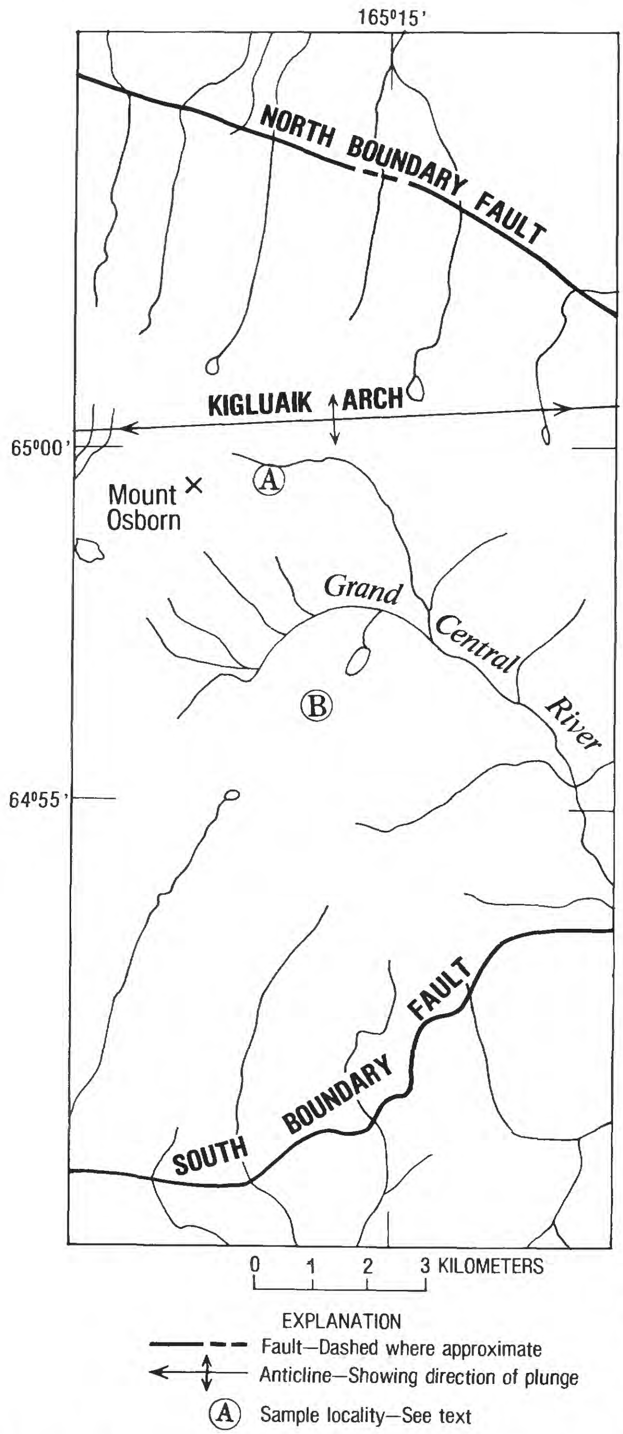

FIGURE 28.—Part of Kigluaik Mountains near Mount Osborn showing major structural features of Kigluaik uplift.

Mineral assemblages diagnostic of granulite facies occur in mafic, ultramafic, and quartzofeldspathic rock types. The assemblages recorded are:

mafic gneiss:	hornblende-plagioclase-hypersthene-quartz
meta-ultramafic rocks:	olivine-clinopyroxene-orthopyroxene-clinoamphibole ± brown spinel
quartzofeldspathic gneiss:	quartz-plagioclase-biotite-clinopyroxene-orthopyroxene-garnet-clinoamphibole

The occurrence of hypersthene in a mafic gneiss (loc. A, fig. 28; fig. 29*A*) indicates granulite-grade metamorphism. The hypersthene is strongly pleochroic, a feature that is common in hypersthene of granulite-grade metamorphic rocks elsewhere. Cummingtonite also occurs in the rock but appears to be a product of retrograde recrystallization.

Granoblastic meta-ultramafic rocks (loc. A, fig. 28; fig. 29*B*) are recrystallized igneous rocks that have probably retained their original igneous mineral assemblages. The assemblages observed, with and without brown spinel, are also characteristic of the granulite facies.

One quartzofeldspathic gneiss layer (loc. A, fig. 28) contains coexisting orthopyroxene, clinopyroxene, and garnet. Because of compositional variation, coexisting garnet and clinopyroxene alone do not always indicate attainment of granulite grade; however, the presence of orthopyroxene removes the possible doubt.

The diagnostic quartzofeldspathic and mafic granulites contain hydrous minerals and thus belong in the hornblende-orthopyroxene-plagioclase granulite subfacies of Winkler (1967). This subfacies is also applicable to the meta-ultramafic rocks, because O'Hara (1967) concluded that an olivine-clinopyroxene-orthopyroxene-amphibole-spinel assemblage, like those discussed above, is stable in the hornblende granulite facies of Fyfe, Turner, and Verhoogen (1958); this facies is equivalent to Winkler's hornblende-orthopyroxene-plagioclase granulite subfacies.

An estimate of the minimum temperature prevailing during metamorphism of the granulites can be inferred from the $MgCO_3$ content of calcite, which was determined to be 11.5 mole percent in an amphibolite-grade calcite-dolomite marble (loc. B, fig. 28). This composition indicates an equilibration temperature for the marble of about 700°C at a pressure estimated to be about 4 kilobars. The granulite-facies rocks can be assumed to have recrystallized at higher temperatures.

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SOUTHWESTERN ALASKA

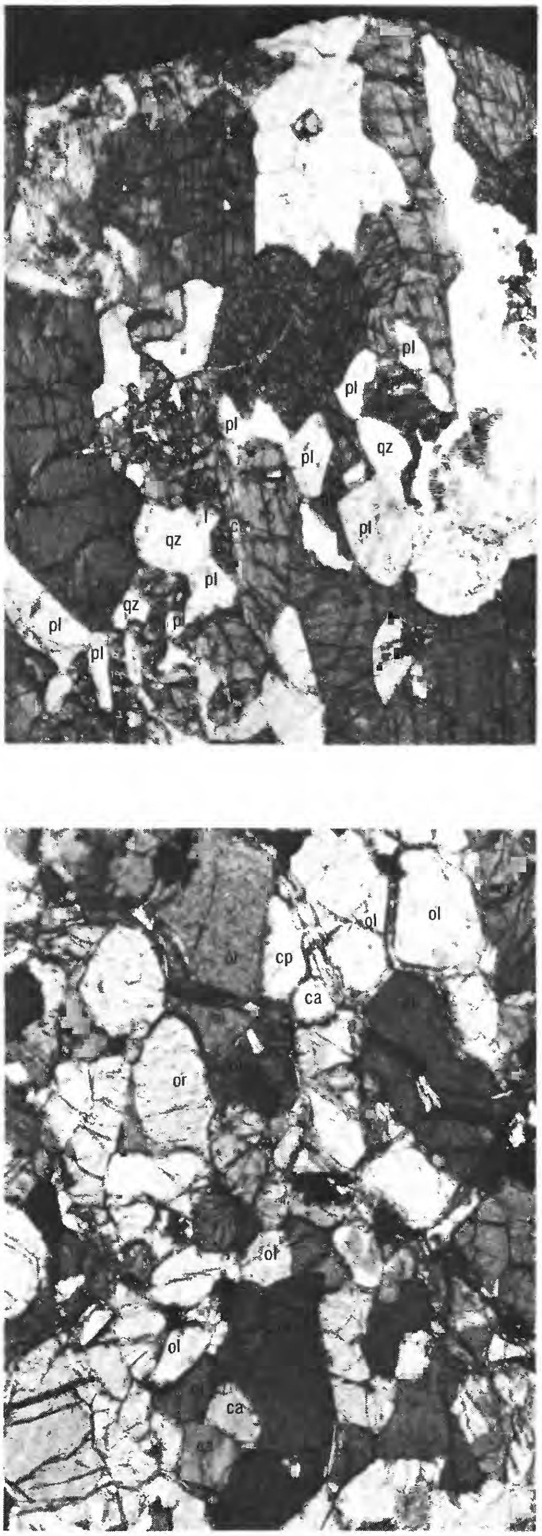
The Kanektok metamorphic complex, a rootless belt of Precambrian rocks in southwestern Alaska

By J. M. Hoare and W. L. Coonrad

An isolated belt of Precambrian rocks in southwestern Alaska is informally referred to here as the Kanektok metamorphic complex. It

A

B



◄FIGURE 29.—Photomicrographs of mafic granulite and meta-ultramafic rocks, Kigluaik Mountains. *A*, Mafic granulite: hb, hornblende; hy, hypersthene; pl, plagioclase; qz, quartz; cu, cummingtonite. (Plane light, 32 ×.) *B*, Meta-ultramafic rock: ol, olivine; cp, clinopyroxene; or, orthopyroxene; ca, clinoamphibole; sp, spinel. (Crossed nicols, 83 ×.)

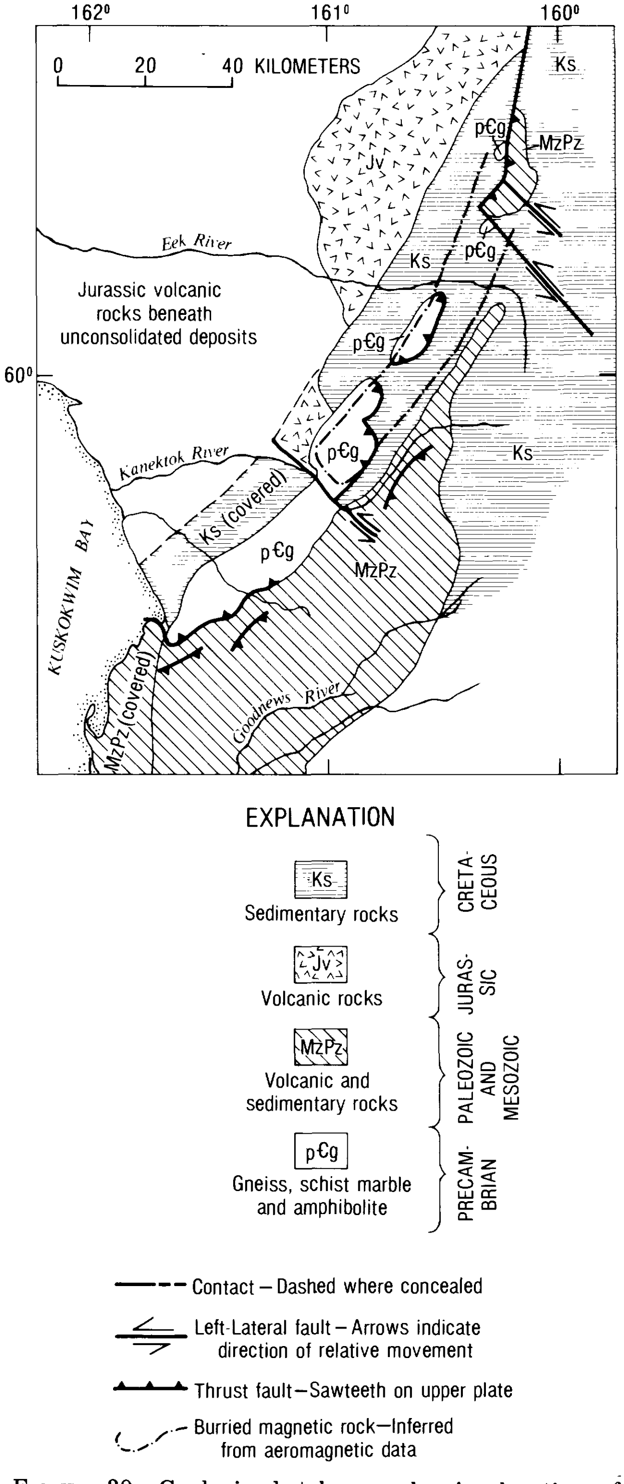


FIGURE 30.—Geologic sketch map showing location of Kanektok metamorphic complex, southwestern Alaska.

trends northeastward across the northwest corner of the Goodnews quadrangle into the Bethel quadrangle and is 160 km long and a maximum of 15 km wide (fig. 30).

The belt was originally mapped as Precambrian (Hoare and Coonrad, 1959, 1961) because the rocks are more metamorphosed than nearby strata of Paleozoic age. More recently, D. L. Turner (written commun., 1977) confirmed the age with more than 50 potassium-argon age determinations. Biotite and hornblende separates have yielded ages ranging from 125 m.y. to 2.5 b.y. Both the youngest and oldest ages were obtained on biotite. The young ages are attributed to metamorphic overprinting. The ages of more than 2 b.y. are possibly caused by the assimilation of excess argon, but the Precambrian age of the rock is assured.

The complex consists of gray quartz diorite, granodiorite gneiss, pink orthoclase gneiss, black garnetiferous amphibolite, marble, and a variety of quartz-mica schists. The rocks are metamorphosed in the upper greenschist and lower amphibolite facies and are completely recrystallized. Although fractured by frost action, they are remarkably fresh and unweathered. Most of the rocks are strongly foliated, but some of the gneisses, particularly in the center of the complex, are massive, nonfoliated rock with a nondirectional "clotty" texture. In general, the character of the rocks suggests that the complex is probably a fragment of ancient continental crust.

The overall shape of the complex is like an elongate "S" trending about N. 30° E. South of the Kanektok River the trend is about N. 50° E. At the river the complex is offset a few kilometers left laterally by one or more northwest-trending faults. North of the river, for a distance of about 25 km, the trend changes to N. 10° E. Farther north it veers back more eastward. Foliation and lineation are parallel to each other and are roughly parallel to the trend of the complex. South of the Kanektok River, the dip of foliation changes from northwest to southwest two to four times across the width of the complex. The rocks are apparently deformed by open folds 1–4 km wide. North of the river the dip and trend of foliation are more variable because the rocks are more highly deformed. They commonly show cataclastic textures and small drag folds. The drag folds rarely trend parallel to the foliation; most of them plunge northwest or southeast across the foliation and lineation. In general, the rocks in the complex appear to be less folded than the Mesozoic and

Paleozoic rocks to the southeast.

Foliation is commonly truncated by small northwest-trending faults. The sense of movement on these faults is not apparent within the complex, but similar faults in younger flanking rocks show left-lateral offset. Smooth tundra-covered slopes are commonly marked by gently dipping lineaments, many of which are the source of springs. The lineaments are tentatively interpreted as low-angle fractures and thrusts. Most of them dip southward; others dip northward.

During the recent (1975–1976) mineral resource investigation, field notes made in 1950 and 1951 were reviewed and the complex was revisited by helicopter. On the basis of this new study, we concluded that the Precambrian metamorphic rocks are thin and rootless and overlie Cretaceous sedimentary rocks. Cretaceous shale crops out at two or three places where the Kanektok River cuts through the metamorphic complex, whereas the ridges on either side are metamorphic rocks. North of the river, valleys that incise the complex are floored by shale or conglomerate of Cretaceous age, but the ridges on one or both sides are gneiss and schist. The obvious interpretation is that the metamorphic rocks are thrust on top of the Cretaceous sedimentary rocks. There are also isolated patches of conglomerate and finer grained rocks in depositional contact on top of the metamorphic complex.

Interpretation (Griscom, 1978) of the aeromagnetic data (Alaska Division of Geological and Geophysical Surveys, 1973a, b; Dempsey and others, 1957) also suggests that the complex is thin and rootless. North of the Kanektok River the metamorphic belt coincides approximately with a broad linear magnetic high, the source of which cannot be the metamorphic belt because it extends across the Cretaceous sedimentary rocks as well. The source of the anomaly is a body of magnetic rock concealed at a depth of 1 to 2 km below the surface (Griscom, 1978). The depth to the magnetic rock decreases northeastward, and the rock that causes the anomaly apparently crops out at Greenstone Ridge. Greenstone Ridge, as the name suggests, consists of altered mafic volcanic rocks and volcanogenic sediments of probable early Paleozoic age (Hoare and Coonrad, 1959).

South of the Kanektok River the metamorphic rocks are characterized by small, steep-sided, low-amplitude anomalies. The shape of these anomalies also suggests that the metamorphic rocks do not continue to depth (Griscom, 1978).

The gravity data support the geologic and aeromagnetic data. Gravity traverses made down the Kanektok and Eek Rivers show a normal increase in the gravity from –20 mgal near the heads of the two rivers to +10 mgal near the coast. There is no evidence in the gravity data indicating a deep-seated body of crystalline rocks.

The Precambrian age and lithology of the Kanektok metamorphic complex are unlike any other rocks known in southwestern Alaska. This, together with its rootless character, suggests that it must have been displaced from somewhere else. However, the source of the complex and how it was transported are still unknown.

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Results of a preliminary paleomagnetic study of volcanic rocks from Nuyakuk Lake, southwestern Alaska

By Susan Karl and J. M. Hoare

During the 1978 field season oriented samples were collected for a paleomagnetic study from a homoclinal sequence of altered basalt flows on Nuyakuk Lake in the Dillingham D–8 and Goodnews D–1 quadrangles, southwestern Alaska

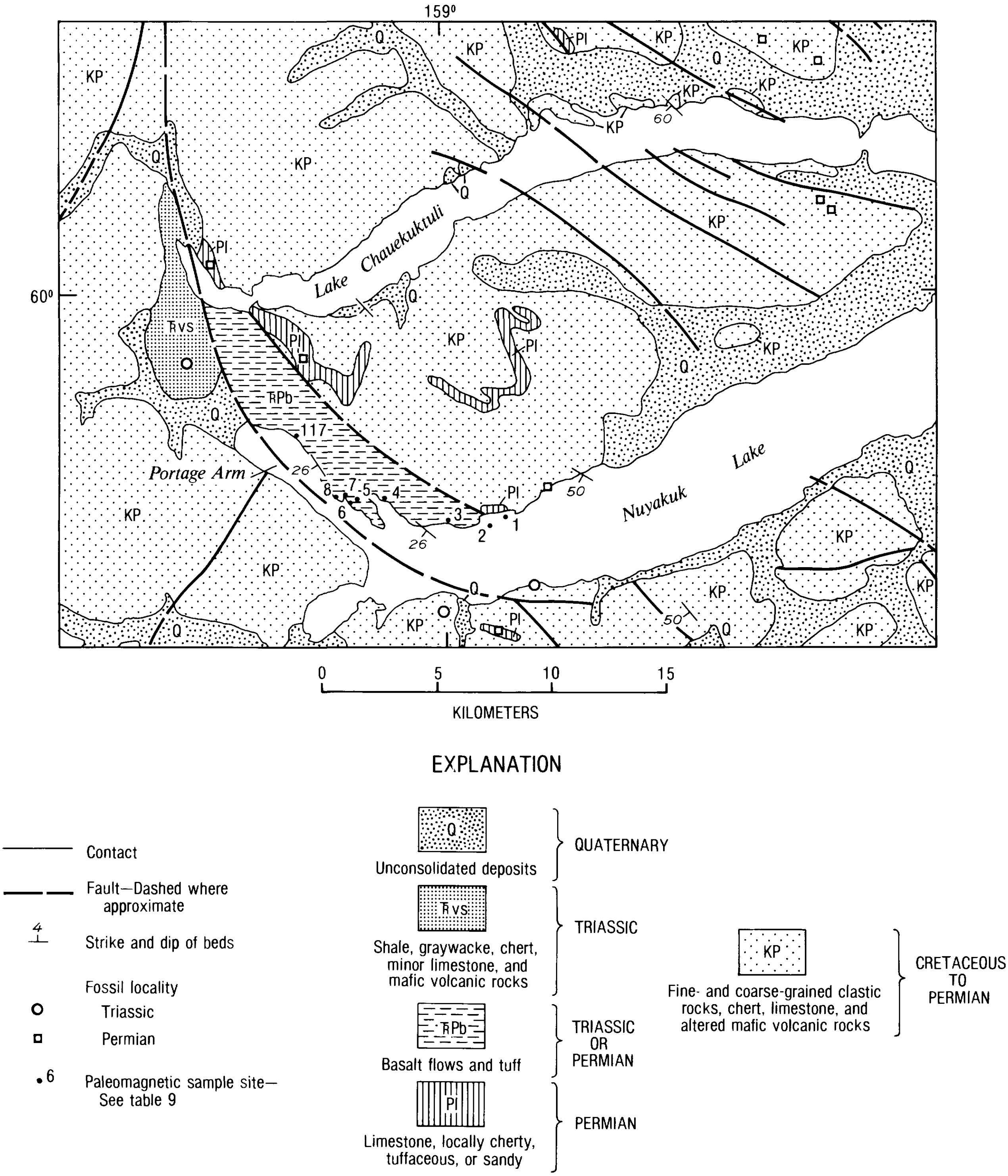

FIGURE 31.—Generalized geologic map showing basalt flows sampled for paleomagnetic study, Nuyakuk Lake, southwestern Alaska.

(fig. 31). The flows strike about N. 45° W. and dip 10° to 25° SW. They underlie an area 3 to 5 km wide and about 15 km long. Their thickness was estimated to be at least 1,500 m (Mertie, 1938, p. 46). However, they are cut by at least one reverse fault and are probably no more than 500 to 1,000 m thick.

The basalt flows are flanked on the southeast side by highly deformed, chiefly sedimentary rocks of Late Triassic age and on the northeast by highly deformed sedimentary and volcanic rocks, most of which are of Permian age. The contacts are known or inferred faults. The basalt consists of massive, commonly columnar-jointed flows, interbedded pillow basalt and pillow breccia, and a minor amount of flaggy, water-laid basaltic tuff. The flows range from dark gray to dark green. Gray flows are less altered and contain relatively little chlorite and epidote. Green flows are more highly altered and have more chlorite, epidote, calcite, and rare prehnite than the gray flows.

Originally the basalt flows were considered to be of Permian age (Mertie, 1938, p. 42–46, pl. 2), and this age assignment was followed by Hoare and Coonrad (1959, 1961). Mertie (1938, p. 37–42) believed that the basalt and limestone on Lakes Nuyakuk and Chauekuktuli were the only rocks of Permian age in the area and that they unconformably overlie rocks of Mississippian(?) age. However, more recently several fossil collections of early Paleozoic and Permian age have been found in the rocks of Mississippian(?) age (J. M. Hoare and H. Condon, unpub. data, 1969–70). Associated mafic volcanic rocks are much more altered and deformed than the basalt on Nuyakuk Lake, which may be younger and are probably of post-Permian age.

A paleomagnetic study was made of 136 cores drilled from 39 oriented samples collected from 10 sites. Cores were demagnetized progressively to 100 milliteslas (mT) in an alternating field along three perpendicular axes, to 145 mT averaged from opposing directions in a four-axis tumbler, and to 610°C in a field-free oven. Combinations of these techniques were applied to test specimens to determine an optimum demagnetization program for each site. The cores were measured on the cryogenic magnetometer at Stanford University. Field directions were determined for samples on the basis of interpretation of intensity curves, magnetic vector plots, directional stability, and internal consistency. Samples were rejected for lack of internal consistency, inability to converge on a stable direction, chaotic vector plots, and extreme noise in intensity plots.

The paleomagnetic directions obtained for each site are summarized in table 9 and figure 32. A paleomagnetic pole of 40° N. and 121° E. was determined for tectonically corrected data. This pole is in good agreement with the Permian paleomagnetic pole of 46° N., 117° E. (McElhinny, 1973, p. 202) calculated for stable North America but differs slightly from the Early and Late Triassic poles.

The reliability of the paleomagnetic pole depends on the strength of the evidence which indicates that the magnetic directions determined represent a stable magnetization acquired when the rocks formed and that all consistent components of secondary magnetization have been removed. The Nuyakuk Lake volcanic rocks vary considerably between sites and within samples in color, density, mineralogy, grain size, and degree of alteration. In addition, secondary minerals observed in thin section, including variable amounts of chlorite, epidote, and rare prehnite, indicate that low-grade metamorphism may have affected these rocks. Similar secondary minerals were observed in the Nikolai Greenstone, and Hillhouse (Jones and others, 1977) concluded that low-temperature prehnite-pumpellyite facies metamorphism is unlikely to

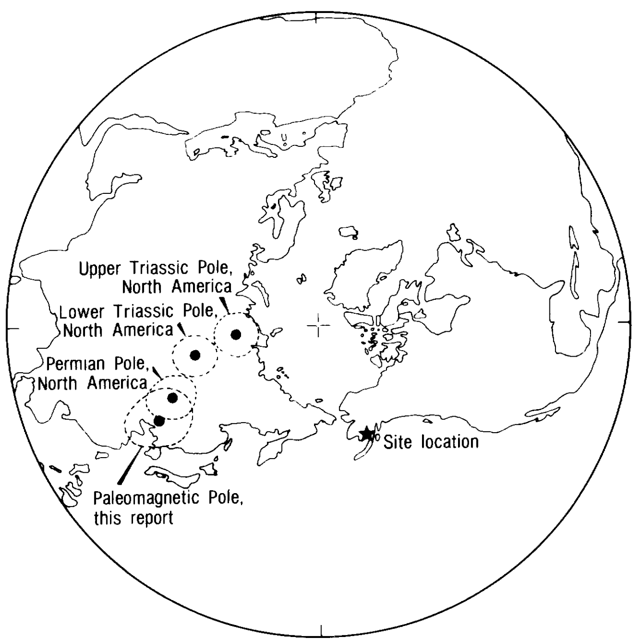

FIGURE 32.—North Polar equal area projection of paleomagnetic poles with ovals of 95 percent confidence McElhinny, 1973).

impose a stable thermal remanent magnetization on the original magnetization of a basalt. The variation in alteration of the basalt was reflected in the different demagnetization programs

TABLE 9.—*Summary of paleomagnetic results*

[N, number samples/site; (x), samples used for that site; H, peak field used during demagnetization; °C, peak temperature used during demagnetization; I_u, uncorrected inclination; D_u, uncorrected declination; I_{tc}, tectonically corrected inclination; D_{tc}, tectonically corrected declination; k, precision parameter; α_{95}, 1/2 angle of 95 percent confidence cone; λ, latitude of Virtual Geomagnetic Pole (VGP); ϕ, longitude of VGP]

Site	N	°C/H	I_u	D_u	I_{tc}	D_{tc}	k	α_{95}	λ	ϕ
PM 1	5(1)	100 mT	-67.6	131.5	-59.4	93.3	22.4	19.8	-35.5	311.5
PM 2	3(3)	225°C/ 100 mT	-53.4	156.1	-55.9	127.5	25.0	25.2	-49.4	279.8
PM 3A	5(3)	80 mT	-57.5	126.5	-67.0	109.1	104.3	12.1	-50.0	309.0
PM 3B	3(3)	50 mT	-59.5	130.1	-69.4	112.2	116.2	11.5	-53.6	311.2
PM 4	4(0)									
PM 5	4(1)	40 mT	-66.3	143.5	-61.6	95.2	2537.5	2.5	-38.4	312.1
PM 6	4(4)	70 mT	-52.6	116.8	-60.5	88.2	89.2	9.8	-34.1	316.2
PM 7	6(6)	300°C/ 100 mT	-44.9	134.9	-35.7	117.4	12.6	19.6	-30.6	277.2
PM 8	4(1)	100 mT	-53.4	108.9	-42.9	89.5	269.3	7.5	-21.1	304.5
PM 117	1(1)	100 mT	-50.86	115.9	-49.0	110.3	231.1	5.0	-35.6	300.3
Mean field direction (nine sites)----			-57.0	128.6	-56.5	105.0	35.5	8.8	-38.7	300.0
Mean VGP (nine sites)---------------------------------------							27.3	10.0	-39.6	301.
			Upper hemisphere--------------------------------						-39.6	121.3
			Permian (McElhinny)--------------				86	7	46	117
			Lower Triassic (McElhinny)--------				89	6	56	104
			Upper Triassic (McElhinny)-------				61	6	68	97

required to converge on a stable direction for each site; the programs required suggest that different components of secondary magnetization were being removed for different sites. Nevertheless, the stable directions ultimately determined for the sites, with a 95 percent confidence level of 8.76, agreed very well. This consistency argues in favor of a primary thermoremanent direction. A fold test indicated that the magnetic directions measured for these samples were acquired prior to folding.

All the field directions measured yielded steep negative inclinations and reversed virtual geomagnetic poles. This fact supports a Permian age for the Nukakuk Lake volcanic rocks, because the Kiaman reversed interval extends for the length of Permian time (McElhinny, 1973, p. 127). If the rocks are Permian, the paleomagnetic results suggest that they have remained in their present position with respect to North America since Permian time. However, the geologic data indicate that the basalt may be post-Permian in age. If they are Early Triassic in age, the determined pole is still consistent with that of stable North America (fig. 32), though a small amount of counterclockwise rotation may be invoked. If the rocks are Late Triassic in age, a small amount of northward translation (5° to 20° of latitude) and possible counterclockwise rotation are indicated. Because the age assignment is uncertain, interpretation of the paleomagnetic results can only be considered tentative. The paleomagnetic data indicate that the Nuyakuk Lake basalt is magnetically stable and would yield potentially useful results if the age of the rocks could be determined with more certainty. An age determination for the basalt, or a paleomagnetic study of the dated limestone, is critical to the interpretation of the paleomagnetic results for the Nuyakuk Lake volcanic rocks with respect to the tectonic history of southwestern Alaska.

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Onset of volcanism at Augustine Volcano, lower Cook Inlet

By David A. Johnston

Augustine Volcano, located on an island in lower Cook Inlet (fig. 1), is a calc-alkaline, dominantly andesitic stratovolcano with an active recent history, which includes major explosive eruptions in 1812, 1883, 1935, 1963–64, and 1976.

Previous geologic studies of Augustine have placed only loose constraints on the age of onset of volcanism. Detterman (1973) and Detterman and Jones (1974) identified Upper Jurassic, Upper Cretaceous, and upper Miocene or lower Pliocene prevolcanic basement rocks on the south side of Augustine Island. Detterman (1973) and Buffler (1976) recognized exotic nonvolcanic boulders of probable Pleistocene age high on the southern slopes, but they were not able to establish the stratigraphic position of the boulders or the age of their deposition.

This paper presents stratigraphic evidence that the boulders were deposited in a proglacial lake, dammed in Cook Inlet during the late Pleistocene Moosehorn glacial advance, approximately 19,000–15,500 B.P. (Karlstrom, 1964), and that volcanism began at Augustine while this lake existed. The rocks erupted during the initial activity were basalt and rhyolite, but all subsequent eruptions thus far recognized emitted rocks of intermediate composition.

Figure 33 illustrates the stratigraphic relations in the most complete and best exposed section through the deposits immediately overlying the prevolcanic basement. This section is exposed between 260 and 320 m above sea level on the boundary between secs. 1 and 2, T. 10 N., R. 25 W., on the south side of the island.

The contact between basement and younger rocks is obscured in this and other sections by surficial deposits. Many exotic boulders, as much as 1 m in diameter, lie on the surface immediately above the basement. These are well-

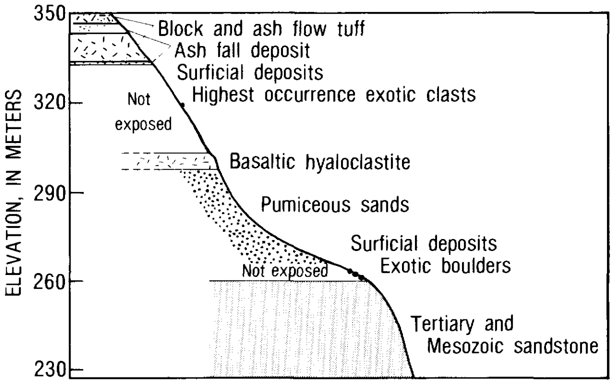

FIGURE 33.—Sketch of section through deposits immediately overlying prevolcanic basement on south side of Augustine Island.

rounded metamorphic and plutonic rocks like those found in the Alaska and Aleutian Ranges west of Cook Inlet. Angular or slightly rounded blocks of sandstone, derived from the basement, are also present, but there appear to be no volcanic blocks that were not carried in from younger deposits upslope. No volcanic rocks were found in place between the boulder-rich surficial deposits and the top of the basement.

The lowest outcrops are exposed about 5 m stratigraphically above the top of the basement rocks. These consist primarily of well-bedded rhyolitic pumice-rich sand, which is interbedded with thin horizons, generally 15–30 cm thick, dominated by well-rounded cobbles and gravel similar in lithology to the boulders at the base of the section. The pumice lapilli are generally angular or slightly rounded, as much as 15 cm in diameter, and are contained in a matrix of broken pumice and nonvolcanic sand. Locally this horizon contains coarse, poorly sorted debris flow deposits, with abundant basement rock fragments, rare metamorphic and plutonic cobbles, and moderately abundant small to large rhyolitic pumice fragments. Cobbles in the debris flow deposits are well imbricated; the individual beds, which are 1 to 2 m thick, show normal size grading of the cobbles; and between the separate beds are conformable 2- to 4-cm-thick fine sand layers (largely nonvolcanic) that are also normally graded. These deposits appear to have been emplaced in standing water.

Above the pumice-rich sand and subaqueous debris flow deposits is a laterally variable horizon of basaltic hyaloclastite breccia that contains cobbles of vesicular basalt as much as 30 cm in diameter in a well-lithified matrix of palagonite. Other types of cobbles, including rhyolite pumice and basement rocks, are a minor component of the breccia. Four outcrops of this unit have been recognized at roughly the same elevation over an area 2 km wide. The easternmost of these is a bedded basaltic sandstone, apparently eroded from the coarser breccia to the west.

Exposures just above the basaltic hyaloclastite are poor, but exotic cobbles and nonvolcanic conglomerate occur in surficial deposits at least 15 m stratigraphically above the top of the basaltic breccia. Above the covered zone, subaerial pyroclastic flow and fall deposits are exposed to the ridge top.

The pumiceous sand, basaltic hyaloclastite, and interbedded nonvolcanic gravel appear to have been deposited in a glacial lake. The elevation at which the deposits occur precludes marine deposition, unless uplift rates are invoked for Augustine Island alone that are very much greater than those inferred for western Cook Inlet during the last 3,000 years (Detterman and Reed, 1973). On the other hand, the elevation at which the deposits occur is consistent with emplacement in a deep glacial lake, several of which existed during the late Pleistocene, as shown by strandlines as high as 300 m above sea level along the east side of Cook Inlet (Karlstrom, 1964). The earliest of these formed during the maximum extent of the Knik Glaciation, roughly 65,000–50,000 B.P., leaving strandlines 300 m above sea level. The next occurred during the maximum extent of the Moosehorn Stade, probably about 17,000–13,500 years B.C., and left strandlines at 230 m elevation. (The age of this maximum is only stratigraphically constrained between 39,000 and 13,000 years B.P. but has been estimated by assuming uniform rates of climatic fluctuation in the late Pleistocene. See Karlstrom, 1964.) Several shallower lakes formed after the Moosehorn glacial advance.

Two lines of evidence suggest that the deposits on Augustine Island were emplaced during the Moosehorn glacial maximum. First the elevation at which the deposits occur is consistent with the 230-m lake level, assuming modern and recent uplift rates (0.3–0.6 m per century on the west side of Cook Inlet, none on the east side; Plafker, 1965; Detterman and Reed, 1973;

Karlstrom, 1964), but they are consistent with 300-m lake levels only if significant subsidence had occurred before onset of recent tectonic uplift at Augustine. Evidence for this along western Cook Inlet is lacking. Second, Karlstrom reports that boulders are concentrated along the unconformity beneath lake deposits of the Moosehorn advance. This evidence agrees with the occurrence of boulders at the base of lake beds on Augustine.

The following conclusions can be drawn from these observations: (1) The proglacial lake of Moosehorn age extended as far southwest as Augustine Island. (2) When boulders at the base of the proglacial lake deposits were emplaced, volcanism had not started at Augustine. Soon after, the volcano erupted rhyolite pumice, followed by basaltic breccia. (3) Judging from the volume and coarseness of the pumice, the initial eruption must have been large and may have produced the widespread ash layer reported by Karlstrom in Moosehorn-age lake beds along eastern Cook Inlet. (4) Eruption of olivine-clinopyroxene basalt during the early history of Augustine is consistent with interpretations presented elsewhere (Johnston, 1978) that andesitic pumices ejected in many recent eruptions are hybrids produced by mixing hydrous basalt with dacitic magmas. The absence of basaltic and rhyolitic ejecta in subsequent eruptions may reflect buffering by a shallow, periodically refilled magma reservoir.

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Revision of the recent eruption history of Augustine Volcano—elimination of the "1902 eruption"

By David A. Johnston and Robert L. Detterman

Coats (1950), in his compilation of volcanic activity in the Aleutians, reported major explosive eruptions of Augustine Volcano in 1883 and 1935, and activity of unspecified nature in 1812 and 1902. Since his compilation, Augustine has had major explosive eruptions in 1963-64 and in 1976. This paper describes the derivation and elaboration within the literature of the "1902 activity" and presents photographic and other evidence that an eruption of Augustine did not occur in 1902.

Coats quoted Sapper (1927), who told nothing more about the activity or about his source of information. Perusal of major Seattle, San Francisco, and New York newspapers published in 1902 disclosed no eruption reports, though the 1935 eruption of Augustine was well reported in the *New York Times.* Detterman (1973), who mapped the volcano after its 1963-64 eruption, referred to unpublished field notes of T. W. Stanton of the USGS, who visted the island July 17, 1904. Those notes may have been the original source for Sapper's statement.

The only reference to activity in 1902 in Stanton's notes is contained in this brief passage:

> It is reported that the volcano had a violent eruption in 1882 [really 1883], and in 1902 there was a large 'mud flow' when one side of the crater broke off and slipped down, according to A. Brown who says he witnessed it from the mainland.

No other primary reference to activity at Augustine in 1902 has yet been found.

Detterman (1973, p. 1) attempted to correlate the reported historic activity with the deposits on the island. On his map he identified a mudflow deposited in 1902. He reinterpreted Stanton's remarks in a reasonable though necessarily speculative manner, and suggested that in 1902 there was "a minor explosion, probably phreatic, in which part of the north crater rim was blown out, accompanied by a large mudflow." Consistent with other historic eruptions of Augustine, he suggested that a dome and spire formed at the conclusion of the 1902 eruption, but that these were largely destroyed in the 1935 and 1963–64 eruptions.

Kienle and Forbes (1976) repeated Detterman's inferences, but they reidentified as a remnant of the 1902 dome part of the dome complex attributed by Detterman to the 1963–64 activity. They further suggested that the 1902 dome and spire were visible in a photograph taken in 1909 but did not identify either in the photograph or provide evidence to support their identification of these features.

Several observations made in recent years undermine some of these inferences about the 1902 activity:

1. A photograph taken of the volcano in the winter of 1961 shows deposits, supposedly of the 1902 eruption (as identified by Kienle and Forbes), that were apparently hotter than the lava dome supposedly emplaced in 1935. Reconsideration of the relation between these deposits, supported by photographic evidence, suggests that the supposed 1902 dome and the 1935 dome were both emplaced in 1935.
2. Lake bottom sediment cores obtained in Skilak Lake on the Kenai Peninsula (Rymer and Sims, 1976) contain ash layers corresponding in age to every reported historic eruption of Augustine, except the "1902 eruption."
3. Careful studies of the tephra stratigraphy on Augustine Island disclosed no recognizable 1902 ash layer.

To test whether an eruption occurred in 1902, a search was made for photographs that showed the summit region of the volcano before and after 1902. Fortunately, two good-quality photographs were obtained from the U.S. Geological Survey Photographic Library in Denver, Colorado, which were taken in 1895, during the first exploration of Augustine by G. F. Becker and C. W. Purington, and in 1904 by T. W. Stanton. The two photographs (fig. 34), both taken from the west and therefore showing the face of the volcano that would have been most modified by the activity as inferred by Detterman and by Kienle and Forbes, show the same skyline profile and the same detail in the snow-filled gullies on the west slope. These, then, confirm that Augustine did not have a significant eruption in 1902. The revised historic activity of Augustine is summarized in table 10.

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A

B

FIGURE 34.—Photographs illustrating appearance of west side of Augustine Volcano. *A*, 1895 (photo by C. W. Purington). *B*, 1904 (photo by T. W. Stanton). Photos were provided by the U.S. Geological Survey Photographic Library, Denver, Colorado.

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TABLE 10.—*Summary of events in historic eruptions of Augustine*

Eruption	precursors	Explosive phase: Initial	Explosive phase: Climax	Later phase	Other comments
1812	?	Ash deposited in Skilak Lake, Kenai Peninsula, 200 km NE of Augustine.		?	"Activity" in 1812 is reported by Doroshin (1879).
1883	Steam visible in August, 1883; frequent earthquakes felt on island days before eruption.	Tephra eruptions one or more days prior to climax?	October 6, 1883: violent explosion, nuée ardente extends >8.6, <12.5 km down north side, impacts inlet, creating tsunami. Nuées continue on all flanks. Summit crater formed, ash deposited in Kodiak and on Kenai Peninsula.	Active lava fountaining continues for more than 2 months, creating 400-foot summit cinder cone. Crater at end of eruption is breached to the north.	3 tsunamis struck English Bay 25 minutes after Oct. 6 eruption; first wave was 30 feet high, was followed at 5-minute intervals by waves 18 and 15 feet high.
1935	?	March 13 through April 3: ash deposited at least as far as Skilak Lake (200 km NE); ash-flows emplaced on north and west flanks of cone., reaching the shore.		Two lava domes emplaced within summit crater.	
1963-64	?	October 10, 1963: ash eruptions with clouds to 4 km, quickly subsided; November 17, 1963, July 5, 1964, August 19, 1964: explosions occurred. Ash deposited in Skilak Lake; ash flows emplaced on N, S, E, and SW flanks.		Former summit crater filled by new lava dome, reaching height of 4300 feet.	
1976	July, 1975: no visible precursors: no change in aeromagnetic field between 1972 and August, 1975; fumarolic emissions at 95°C or less, consist of meteoric water. Steam issues from margins and flank of 1964 lava dome. October, 1975: began increased seismicity 6 km deep; late Oct., steam explosions began; ca. Dec. 20, 1975 seismic network on island ceased to operate; Jan. 21-22, 1976: seismicity increased on off-island network.	January 22, 1976: small explosions at 7:59, ca.16:30, 22:19 AST. Eruption clouds to 4-5 km; first ash fall at Lake Iliamna, evening of January 22. Large seismic swarm from 8:00 to 22:00 AST, January 22. Summit crater formed in initial explosions?	Major eruptions: January 23: 6:58, 7:40, 16:18, Jan. 24: 8:38, Jan. 25: 4:56 AST, plus several more smaller "steam explosions;" eruption columns to 14 km. Ash flows deposited on all flanks, especially north side, where ash flows extend beyond the shoreline. Ash fall on Iliamna area, Kenai Peninsula, Anchorage area, Valdez, and minor ash in Sitka. Quiescent Jan. 26 to Feb. 6; starts again with ash fall on Kenai Peninsula plus new ash flows on all flanks, reaching shoreline to northeast. Pyroclastic flows emplaced by collapse of vertical eruption column.	Lava dome appears in summit crater by Feb. 12; growth of dome continues through late Feb., accompanied by incandescent block-and-ash avalanches on north flank below dome only. Pyroclastic flows emplaced by dome collapse. After 1½ months of quiescence, minor explosions occur in summit region during mid-April, accompanied by more growth of lava dome and emplacement of more block-and-ash avalanches.	Summit crater, formed at beginning of eruption, was breached to north and controlled emplacement of subsequent block-and-ash-avalanches. Nuées ardentes in January were accompanied by devastating high-temperature, high-velocity shock waves that advanced more than 1.5 km beyond the ash flow basal avalanche deposits. Total volume produced in 1976 eruption: 0.21 km^3 of which 26% is ash fall, 43% is pyroclastic flows, 31% is lava dome. 39% was emplaced in January, 49% in February, and 12% in April.

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Volcanic gas studies at Alaskan volcanoes
By David A. Johnston

Approximately 40 Alaskan volcanoes have erupted within historic time, and 30 more have erupted since the Pleistocene (Coats, 1950). Many of these have erupted violently and constitute a hazard. Despite the danger, little effort has been made to monitor the activity of Alaskan volcanoes beyond spotty seismic monitoring primarily designed for regional earthquake studies.

In 1976, during the eruption of Augustine Volcano, a program was started to determine the distribution and geology of thermal and fumarolic areas on Alaskan volcanoes and to determine the temperature and composition of fumarole emissions from these volcanoes, in order to provide background data against which possible precursor changes could be compared. This work has centered primarily upon Augustine Volcano, where additional goals have been: (1) to define the preeruption volatile-element content of Augustine's magmas, largely by electron probe studies of glass inclusions in phenocrysts; and (2) to observe the changes in fumarole emissions as the 1976 deposits cool. Since its start, this study has been expanded to include Redoubt and Iliamna Volcanoes, north of Augustine, and Mounts Griggs, Mageik, and Trident, and Novarupta Dome in Katmai National Monument, southwest of Augustine. Gas analyses are being performed in cooperation with A. H. Truesdell and N. Nehring of the U.S. Geological Survey, Menlo Park, California. This paper describes the setting and temperatures of fumaroles on these volcanoes and presents some preliminary analytical results.

In July 1977 Redoubt Volcano emitted gas from weakly effusive fumaroles on the dome emplaced during its most recent eruptions (1966–68). The gas was escaping at and below the boiling temperature of water and was nonsulfurous. No sublimates were observed near any active steaming ground.

Iliamna Volcano has very active fumaroles on its steep northeast and east faces, approximately 150 m below the summit. These could not be reached because of hazardous access, but a strong SO_2 odor is apparent in their vicinity, and yellow sublimates surround each vent. Because of the high volume and rate of emission of gas from Iliamna's fumaroles, a pronounced steam plume sometimes rises above the summit, particularly on cold clear days. Such plumes can be mistaken for eruption clouds or "steam eruptions," as appears to have been the case in November, 1978 (Smithsonian Scientific Event Alert Network Bulletin, v. 3, no. 12), when a "steam eruption" was reported on a particularly calm, clear, cold day by an observer in Anchorage.

During the summer before its 1976 eruption, Augustine emitted gas at or below boiling temperature from fumaroles on the surface and margin of the dome emplaced in 1964. In the only location sampled, the gas consisted of reheated rainwater without sulfur (Johnston, 1978). Since the 1976 eruption gas has been emitted from the surface and margins of the 1976 dome, from 1976 pyroclastic flow deposits, and from a few locations on the lower, older flanks of the cone. Most fumarole temperatures have declined dramatically since the eruption; maximum temperatures on the pyroclastic flow deposits fell from 605°C (February 26, 1976) to 433°C (August 20, 1976) to boiling temperature by July 25, 1977. Fumarole temperatures on the lower flanks of the new dome dropped from 550°C maximum (August 20, 1976) to 110°C maximum by August 1978. Fumaroles at the base of the apical spine, emplaced during the final phase of eruptive activity in April 1976, were still emitting gas at approximately 650°C when first visited in August 1978. Fumaroles on the dome continued to emit SO_2 through August 1978, although the SO_2 content of those on the pyroclastic flow deposits fell below detection limits by July 1977. The volume of emissions declined dramatically between 1976 and summer 1977, primarily because large parts of the dome surface ceased gentle steaming.

Thermal manifestations at Mount Trident are spatially related to the satellitic vent on the south side of the main cone. Several andesitic lava flows issued from this vent between 1953 and 1968 (Wilson and Forbes, 1969). Fumaroles on the top of the satellitic cone are SO_2 bearing and do not exceed boiling temperature. A fumarole on the southwest ridge of the main cone, active in 1916 (Griggs, 1922), appears now to be inactive. CO_2-rich springs, a few degrees above ambient temperature, occur south of the satellitic cone, near Mageik Creek, and hot springs, emitting water at a maximum of 50°C, occur just east of one of the recent lava flows. The hot springs have existed since before 1917 (Griggs, 1922).

Several weakly effusive fumaroles are active on Novarupta Dome, emplaced at the conclusion of the 1912 eruption that formed the Valley of Ten Thousand Smokes. A few weak fumaroles still remain in the upper part of the valley as well, especially along ring fractures related to the Novarupta collapse caldera and fractures radial to the dome and caldera (G. Curtis, E. W. Hildreth, and D. A. Johnston, unpub. data, 1978). These emit predominantly water vapor, with no sulfur odor, at or below boiling temperature.

Gas is emitted from several vigorous fumaroles and many smaller fumaroles and mudpots within the central crater of Mount Mageik. The crater appears to have formed by explosive reaming of an earlier dome or flow during a prehistoric eruption. The crater in 1978 closely resembled its appearance in 1923, when it was visited and photographed by Fenner (1930). This similarity argues against reports of an eruption from this vent in 1929 (Coats, 1950). Since 1923 a small lake has formed within the crater, and the water of that lake was 70°C and had pH less than 1.0 in July 1978. Fumaroles, all at or near boiling temperature, emit abundant SO_2, accounting for the acidity of the lake.

Like Mount Mageik, Mount Griggs emits SO_2-rich gas at boiling temperature. The sulfur content is sufficiently high that the gas plumes are yellow within 1–2 m of their vents, which have constructed sulfur mounds. Rates of emission are so high on Mount Griggs that the roar of the largest fumarole can be heard from the valley floor. The fumaroles occur in a linear belt on the southwest flank of the cone, 250 m below the lip of the summit crater, and come up through surficial talus and breccia, which prevent observations of underlying rock structure necessary to account for their presence.

Although major compositional differences exist between the emissions of the volcanoes studied, SO_2 rather than H_2S is the dominant sulfur gas at all the volcanoes that emit sulfurous gas. H_2S is dominant in the gas emitted by Cascade volcanoes of Washington and Oregon, and the compositional difference between the two types appears to indicate that the gas from Alaskan volcanoes is, in general, equilibrating at higher temperatures than gas emitted by Cascade volcanoes (Ellis, 1957).

It is not safe, however, to assume that the gas emitted from these volcanoes equals the composition of volatile elements within subsurface magma chambers. Primarily by examining the composition of glass inclusions in phenocrysts (Anderson, 1973; Johnston, 1978), estimates have been obtained for the abundance of water (estimated "by difference" with the electron probe), chlorine, sulfur, and fluorine in the magmas involved in Augustine's 1976 eruption. The basalt contained roughly 3.5 weight percent water, 0.25 weight percent chlorine, and less than 0.01 weight percent fluorine and was saturated with sulfide. The dacite magma was saturated with respect to a chloride- and water-rich vapor phase and sulfide liquid and contained about 6.5 weight percent water, 0.5 weight percent chlorine, less than 0.01–0.02 weight percent fluorine, and 0.01–0.04 weight percent sulfur (Johnston, 1978).

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Paleozoic rocks on the Alaska Peninsula

By Robert L. Detterman, James E. Case, and Frederic H. Wilson

Two small areas of middle Paleozoic limestone were discovered near Gertrude Creek, 16 km north of Becharof Lake on the Alaska Peninsula, during reconnaissance flying as part of the Alaska Mineral Resource Assessment Program (AMRAP) for the Alaska Peninsula. Previously, the only known occurrence of Paleozoic rocks on the Alaska Peninsula was a small exposure of middle Permian limestone on an island at the entrance to Puale Bay (Hanson, 1957). This is the first reported occurrence of middle Paleozoic rocks in what is considered to be a Mesozoic and Tertiary province.

The larger of the two exposures of limestone forms a low hill about 275 m high and 1.5 km long between Gertrude Creek and King Salmon River (fig. 35). The second outcrop forms a ridge top about 1 km southwest of the limestone hill. The exposures are in secs. 27 and 33, T. 23 S., R. 42 W., Seward Meridian, about 6 km west of the boundary of Katmai National Monument.

The light-gray medium- to coarse-grained limestone of both exposures is mainly medium bedded to massive and contains small chert nodules and thin interbeds of dark-gray finely crystalline limestone. The rock has been slightly thermally metamorphosed and recrystallized to a sugary texture. In the northeastern hill, bedding is still distinct and dips 30° to 55° northwest, exposing several hundred meters of limestone. The southwestern mass is nearly all massive and is somewhat more metamorphosed. Several dikes cutting the rock in the northeastern hill have introduced pyrite and magnetite to the limestone and have altered the wallrock. The andesitic composition of the dikes suggests that they are similar to dikes cutting the granodiorite batholith and are not related to emplacement of the batholith.

The northeastern body of limestone contains poorly preserved corals and gastropods. The corals were examined by A K. Armstrong and W. A. Oliver, Jr., U.S. Geological Survey, who stated:

> The corals are favositids probably *** members of the *Favositidae*. The several specimens seem to belong to only one species. They are similar to, but larger than, specimens illustrated as *Pachyfavosites* in Professional Paper 823-B, pl. 6, figs. 5 and 6, and pl. 20, figs. 3-6 (Oliver, Merriam, and Churkin, 1975). The probable range of this general type of coral is Late Ordovician to Devonian, but more likely the specimens are Silurian to Middle Devonian. (written commun., 1978).

E. L. Yochelson, U.S. Geological Survey, reported the gastropod was so fragmented that it was generically indeterminate, but it probably was *Bellerophon* of Devonian age (written commun., 1979). Several samples were processed for conodonts, but none were found.

Although the age of the limestone cannot be precisely determined from faunal remains, the evidence strongly suggests a Silurian or Devonian age. Inasmuch as the particular type of corals collected are unknown from upper Paleozoic rocks, these limestones are considered to be middle Paleozoic, and probably Silurian or Devonian. These are the first reported from the Alaska Peninsula and are the southernmost exposures of middle Paleozoic rocks in southwestern Alaska.

The two limestone bodies are probably roof pendants in the Alaska-Aleutian Range batholith. The southwesternmost of the two limestone areas is surrounded by a biotite-hornblende granodiorite; the granodiorite is exposed also near the northern mass. Two potassium-argon dates are available for this granodiorite at Blue

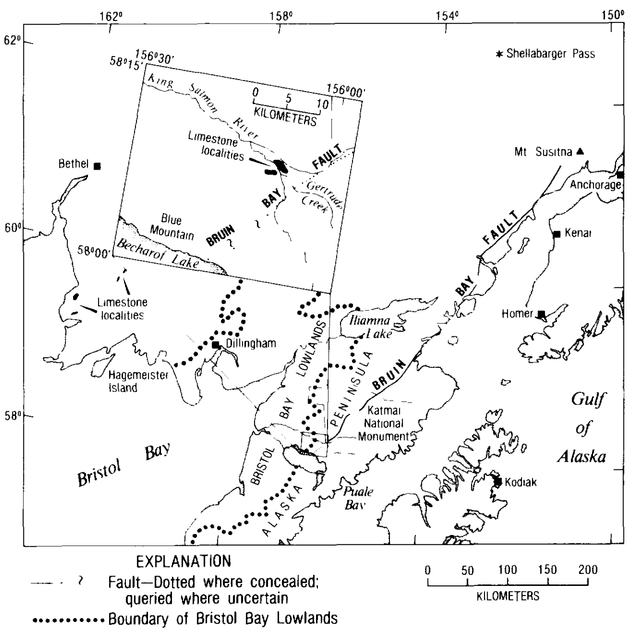

FIGURE 35.—Location of middle Paleozoic limestone, southwestern Alaska.

Mountain, 16 km southwest of the limestone. The samples were dated at 163 and 166 m.y. (Reed and Lanphere, 1972) and thus are part of the Middle Jurassic batholith that is exposed for about 400 km along the west flank of the Alaska and Aleutian Ranges. Roof pendants are fairly common in the Alaska-Aleutian Range batholith; several have been mapped in the Iliamna quadrangle about 200 km northeast of this locality (Detterman and Reed, 1979).

The limestone crops out about 3 km west of the projected trace of the Bruin Bay fault, a major fault system that extends from Becharof Lake about 500 km northeastward to Mount Susitna, near Anchorage. Along part of this distance, the batholith and associated roof pendants have been thrust southeastward over Mesozoic sedimentary rocks southeast of the fault. The presence of small limestone bodies near Gertrude Creek may indicate that larger masses are buried at drillable depths to the west under Bristol Bay lowlands or under Bristol Bay.

The limestone bodies near Gertrude Creek are lithologically similar to and contain the same corals as highly fossiliferous limestone at Shellabarger Pass, about 550 km to the northeast in the Alaska Range (Reed and Nelson, 1977) and are lithologically similar to Devonian limestone in the Hagemeister Island and Goodnews quadrangles 320 m to the northwest (Hoare and Coonrad, unpub. data, 1978). It is not clear whether southward extension of middle Paleozoic limestone to Gertrude Creek signifies extensive bodies of limestone in southwestern Alaska or whether these are merely small fault-positioned occurrences.

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Hydrocarbon reservoir and source rock characteristics from selected areas of western Alaska

By I. F. Palmer, J. G. Bolm, T. Flett, W. M. Lyle,[6] J. A. Morehouse,[6] J. Riehle,[6] and K. S. Emmel[6]

A joint State of Alaska/U.S. Geological Survey field project conducted during July 1978 in selected areas of western Alaska, including Nelson and Nunivak Islands, has resulted in considerable new data on petroleum reservoir and source rock potential. Six stratigraphic sections were measured, totaling 2,235 m. Samples collected from these stratigraphic sections totaled 236.

Laboratory analyses indicate that C15+ soxhlet extraction for hydrocarbons range from 6 to 99 ppm (parts per million) and averaged 48 ppm. Only 13 samples of the 69 processed had an organic content of more than 0.5 percent carbon. On the basis of the thermal alteration index method, most samples plot in the upper immature to mature range; however, the extractables indicate only a "lean" organic source rock potential. Reservoir potential is also considered marginal because all samples have less than 10 percent porosity and less than 1 millidarcy permeability. Stratigraphic sections, laboratory data, and a complete report will be published by the State of Alaska Division of Geological and Geophysical Surveys.

SOUTHERN ALASKA

Plutonism and regional geology in southern Alaska

By Travis Hudson

Data on the distribution, geologic setting, petrology, and age of calc-alkaline plutonic rocks in southern Alaska (Hudson, in press) show that southern Alaska plutonism has been episodic and that plutons of specific ages were

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emplaced in linear to curvilinear belts that are now subparallel to the continental margin. These belts have important general implications for the Mesozoic tectonic history of southern Alaska (Hudson, 1979), but they also help to identify several more specific problems in southern Alaska regional geology. These problems deal primarily with the spatial continuity of the plutonic belts, but temporal overlap of plutonism in some belts raises additional questions. These problems or questions, outlined separately below, should be addressed in future studies of southern Alaska regional geology.

1. Do Early Jurassic (Late Triassic?) plutonic rocks of Kodiak Island and southern Kenai Peninsula (Kodiak-Kenai belt) extend northeastward along the northern flank of the Chugach Mountains? Much additional information is needed from throughout the coastal mountains to clarify the regional relations and significance of this plutonic episode in southern Alaska.

2. Are Middle and Late Jurassic plutonic rocks of the Aleutian Range and Talkeetna Mountains (Aleutian Range-Talkeetna Mountains belt) continuous across the Susitna lowlands? As presently drawn, the map pattern of this belt suggests discontinuity between the Aleutian Range and Talkeetna Mountains segments and significant right-lateral displacement along the Castle Mountain fault.

3. How do Jurassic plutonic rocks near Tonsina and areas eastward to Chichagof Island (Tonsina-Chichagof belt) relate to other Jurassic rocks in southern Alaska? Is the Tonsina-Chichagof belt an extension of the Aleutian Range-Talkeetna Mountains belt?

4. Is the region containing Late Cretaceous and early Tertiary plutonic rocks in the Alaska Range and Talkeetna Mountains (Alaska Range-Talkeetna Mountains belt) terminated northward by the Denali fault system? Available data indicate that it is. If so, where is the continuation of the Alaska Range-Talkeetna Mountains belt north of the fault system? Is it the northern part of the Coast Range batholithic complex in British Columbia and Yukon Territory?

5. Why is there overlap in age between early Tertiary plutonism in the Alaska Range-Talkeetna Mountains belt and early Tertiary plutonism along the Gulf of Alaska margin (Sanak-Baranof belt)? The Alaska Range-Talkeetna Mountains belt probably formed, at least in part, in response to northerly directed subduction along the continental margin (Hudson, 1979), but the early Tertiary plutons of the Sanak-Baranof belt probably had a different origin (Hudson and others, 1977). The early Tertiary plutons of the Alaska Range-Talkeetna Mountains belt mark a shift to a broader western zone of plutonism that is more felsic than Late Cretaceous plutonism in the same belt. Did subduction stop or slow down considerably by the early Paleocene? Were early Tertiary plutons of both the Alaska Range-Talkeetna Mountains belt and the Sanak-Baranof belt emplaced as a result of anatexis at crustal levels after an episode of subduction?

The above are some of the more specific regional geologic questions that evolved from the synthesis of southern Alaska plutonic rock data. A more general question deals with the timing of subduction and strike-slip modes of plate motion along the Mesozoic and Cenozoic continental margin. If we assume that southern Alaska plutonic belts formed in response to plate convergence and subduction (most, but not all, probably did), then the time of pluton emplacement may be approximately the same as the time of subduction. If we assume continuous plate motion, then the intervals between plutonic episodes are those most likely to have been characterized by strike-slip faulting.

There are some obvious problems with this simplified but necessary first step in identifying a temporal framework for the tectonic history of southern Alaska: (1) in a region as large as southern Alaska, subduction and strike-slip faulting can occur simultaneously, as is happening today; (2) the timing of southern Alaska plutonism is still incompletely known, and the relation of most southern Alaska plutonism to subduction is not entirely clear; (3) some plutonic belts that are now a part of southern Alaska may have actually formed somewhere else, rather than along the Alaska continental margin; and (4) relative plate motion need not have been continuous throughout the Mesozoic and Cenozoic. However, because our knowledge of southern Alaska geology is in the development stage, the general relations suggested in figure 36 can serve as an initial temporal framework for examining the regional geology. Is there evidence of the suggested shifts and

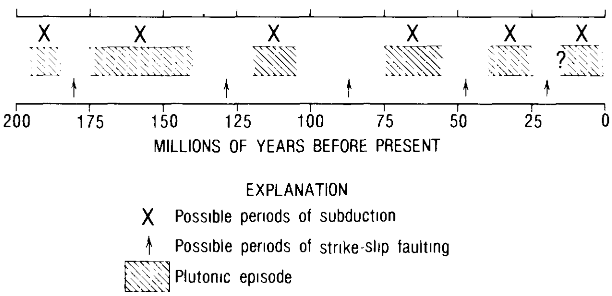

FIGURE 36.—Diagrammatic representation of plutonic episodes in southern Alaska.

timing of southern Alaska subduction and strike-slip faulting in the rock record? Testing of these possibilities should lead to refinements or revisions that clarify the tectonic history of southern Alaska.

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Early Cretaceous radiolarians from the McHugh Complex, south-central Alaska

By Susan Karl, John Decker, and David L. Jones

Age-diagnostic radiolarians of Early Cretaceous age were separated by hydrofluoric acid leaching from bedded red chert collected from the type locality of the McHugh Complex along the Seward Highway near Anchorage, Alaska (fig. 37). The McHugh Complex is a chaotic assemblage of weakly metamorphosed clastic sedimentary and volcanic rocks which locally serve as a framework or matrix for irregularly sized blocks and clasts of marble, chert, granitic rocks, and mafic and ultramafic rocks. Clark (1972; 1973, p. D2) considered the McHugh Complex to be Late Jurassic and (or) Cretaceous on the basis of a potassium-argon hornblende age of 146 ± 7 m.y. obtained from a granitic cobble from a metaconglomeratic sandstone within the type locality. Plafker and others (1976) included the McHugh Complex in the melange facies of the Chugach terrane, which is known to contain Lower Cretaceous radiolarian cherts on Kodiak Island and in southeastern Alaska (Plafker and others, 1977). The Early Cretaceous radiolarians from the type locality of the McHugh Complex support the correlation of the rocks in these three areas as suggested by Plafker and others (1976).

The chert from the McHugh Complex is here considered Valanginian on the basis of the age ranges of the following radiolarian species: 1) *Dictyomitra apiarium* Rüst, Berriasian to Barremian (Foreman, 1975), 2) *Parvicingula citae* Pessagno, Valanginian (Pessagno, 1977), 3) *Podobursa triacantha*(?) Fischli, late Valanginian (Foreman, 1975; Pessagno, 1977), 4) *Sethocapsa cetia* Foreman, Berriasian to Valanginian (Foreman, 1975), and 5) *Stichocapsa*(?) *rotunda* Hinde, Berriasian to Valanginian (Foreman, 1975).

The sampled chert, found by Travis Hudson of the USGS, is located at the benchmark (BM 39) in sec. 15, T. 11 N., R. 3 W., in the Anchorage A–8 quadrangle and consists of a moderately well exposed block approximately 1 m by 2 m associated with altered mafic volcanic rocks. The volcanic rocks are massive and locally show crude pillow(?) structures. The contacts between the chert block and the surrounding volcanic rocks are covered. Smaller beds of chert were found in the vicinity of the sample site, but they did not yield radiolarians. Some red chert and volcanic rocks are intimately mixed; probably the mixing occurred while the chert was soft radiolarian ooze and it is therefore approximately the same age as the volcanic rock. Unfortunately, where these contact relations are observed, the chert is recrystallized—probably owing to the heat of the volcanism—and does not yield radiolarians. In any case, the close association of basaltic volcanic rock and chert in the McHugh Complex supports the suggestion of Jones and others (1978) that oceanic (ophiolitic?) rocks of late Mesozoic age were structurally incorporated within an accretionary belt that extends from Vancouver Island on the south to Kodiak Island on the north, a distance of over 1,500 km.

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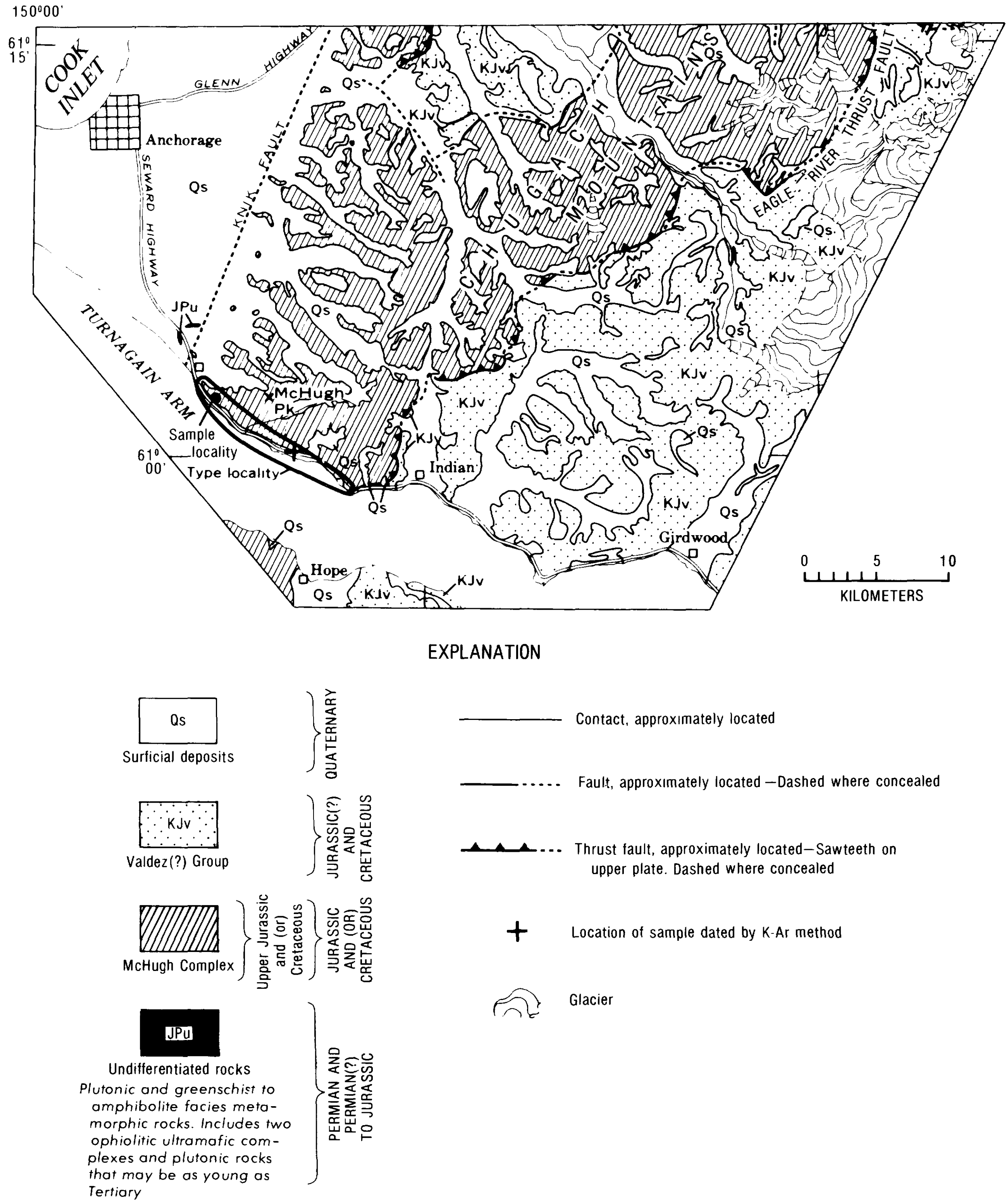

FIGURE 37.—Map showing sample location and generalized distribution of McHugh Complex near Anchorage, Alaska. (Modified from Clark, 1973.)

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Regional significance of tectonics of the Talkeetna Mountains, south-central Alaska

By Béla Csejtey, Jr.

The Talkeetna mountains are part of the geologically diverse terrane of southern Alaska which developed by the accretion of several allochthonous, continental or continentalized crustal blocks to the ancient North American plate (Richter and Jones, 1973; Csejtey, 1974) in late Mesozoic time (Csejtey, 1976; Jones and others, 1977; Csejtey and others, 1978; Jones and others, 1979). Although the exact number and extent of these allochthonous blocks are imperfectly known, they appear to have moved considerable distances northward prior to their collision with the ancient North American plate (Jones and others, 1977; Hillhouse, 1977). Completion of reconnaissance geologic mapping of the Talkeetna Mountains (Csejtey and others, 1978), and of the Chulitna district just to the northwest (Silberling and others, 1978; Jones and others, 1979), yielded structural and stratigraphic data that not only lend credence to the accretionary concept of southern Alaska but also provide evidence for the time, method, and direction of emplacement of the crustal blocks after their collision with the ancient North American plate.

Most of the structural features in the Talkeetna Mountains and Chulitna district are the result of a middle to Late Cretaceous alpine-type orogeny. Its age has been reliably determined by the age of the youngest deformed rocks (Early Cretaceous), and by the ages of the oldest undeformed intrusive rocks (Late Cretaceous and Paleocene) (Csejtey and others, 1978). The orogeny involved multiple thrusting and folding, high-angle faulting, shearing, subordinate metamorphism, and post-tectonic plutonism. This deformation caused a pronounced northeast-trending structural grain. In the Talkeetna Mountains the vergence of this structural grain is steeply to moderately toward the northwest, but in the Chulitna district it abruptly reverses toward the southeast with steep attitudes. The intensity of the deformation is greatest in the Chulitna district and northwestern two-thirds of the Talkeetna Mountains (fig. 38), but it rapidly decreases toward the southeast. Folds within the intensely deformed area generally are tight and isoclinal and range in size from small secondary folds to megafolds having an amplitude of several kilometers. The larger folds commonly have a well-developed axial plane slaty cleavage with fine-grained secondary sericite or biotite, and their limbs are commonly sheared or faulted out.

The most important structural feature of the region is the steeply southeastward-dipping Cretaceous Talkeetna thrust, which trends northeasterly across the Talkeetna Mountains. It is located within but near the southeastern margin of the area of intense deformation. The thrust brings, on the south, upper Paleozoic and Triassic rocks of the allochthonous crustal block "Wrangellia" (Jones and others, 1977) against Lower Cretaceous flyschlike sedimentary rocks, which underlie large areas not only in the northwestern Talkeetna Mountains and the Chulitna district but also in the western part of southern Alaska. Because of their lithologic characteristics, age, and distribution (Csejtey and others, 1978), these flyschlike rocks are interpreted to be continental margin-type deposits that have moved only short distances in comparison with "Wrangellia."

Other important Cretaceous thrusts occur in the Chulitna district and in the northwestern corner of the Talkeetna Mountains. In the Chulitna district a number of northeast-elongated thrust slivers, folded into a large southeastward-

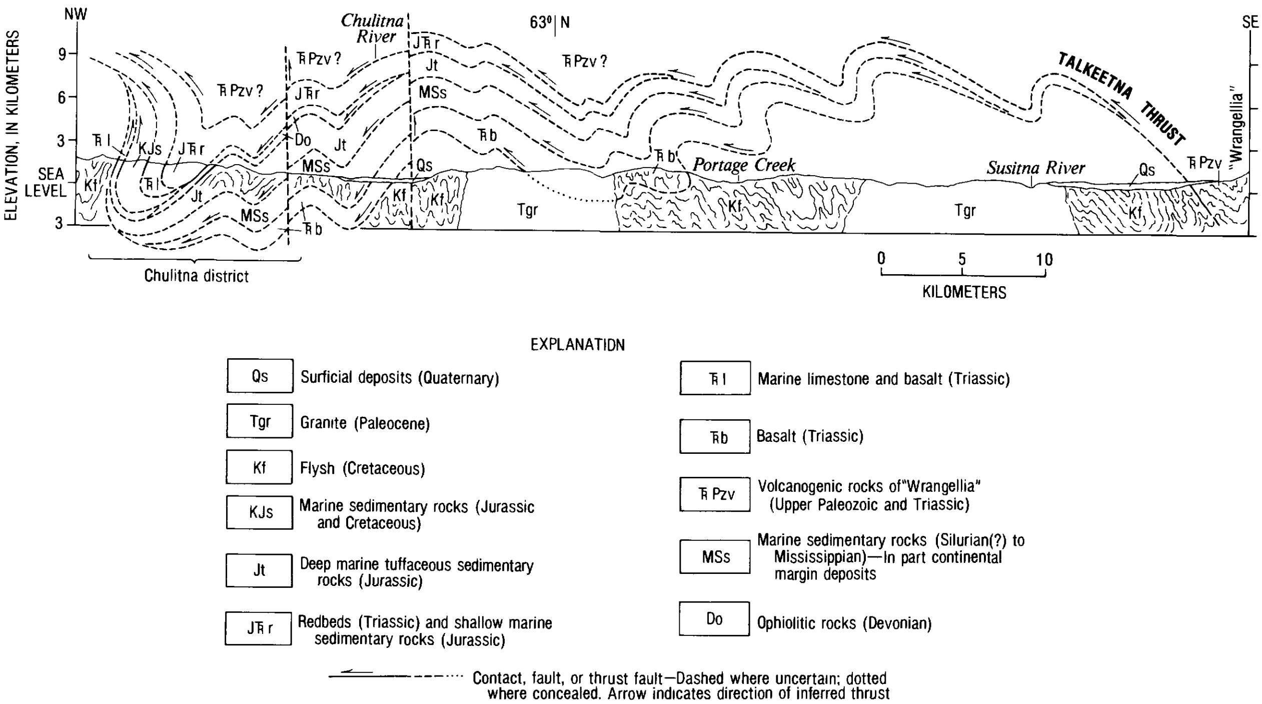

FIGURE 38.—Interpretive structure section across Chulitna district and northwestern Talkeetna Mountains, south-central Alaska. Thrusts and folds are schematic.

overturned syncline, bring together on the top of the Cretaceous flysch a wide variety of rock sequences of different ages and depositional environments (Silberling and others, 1978; Jones and others, 1979). These sequences range in age from Silurian or Devonian to Jurassic and Cretaceous and include such diverse rocks as dismembered ophiolites, continental margin-type deposits, and nonmarine red beds. None of these rocks is part of "Wrangellia" or is known to occur elsewhere in Alaska.

The thrusts in the northwest corner of the Talkeetna Mountains outline a well-exposed composite klippe more than 50 km across. This klippe, an excellent example of the style of the Cretaceous deformation, comprises Upper Triassic basalt thrust upon the Lower Cretaceous flyschlike rocks that themselves were thrust upon the basalts. The whole sequence has been compressed into a gigantic northwestward-overturned fold with a wavelength of about 25 km and an amplitude conservatively estimated as at least 10 km. According to D. L. Jones (oral commun., 1978), these basalts do not correlate with any rocks of either "Wrangellia" or the Chulitna district.

The geologic data from the Talkeetna Mountains and the Chulitna district rather strongly indicate that all rocks in these regions which predate the Lower Cretaceous flysch are allochthonous and that they were emplaced by northwestward thrusting in middle to Late Cretaceous time. The geologic map of the Talkeetna Mountains rather convincingly suggests that the eroded thrust plates in the Chulitna district and in the northwest corner of the Talkeetna Mountains are not rooted somewhere southeast of the block "Wrangellia" but in the fault separating "Wrangellia" from the semi-autochthonous Cretaceous flysch, that is, in the Talkeetna thrust. Thus, these thrust plates are interpreted to be lenticular, imbricated thrust slivers of the Talkeetna thrust, emplaced by the bulldozing action of the much larger, northwestward-moving "Wrangellia" block. The absence of volcanic arc and trench assemblage rocks suggests that the allochthonous rocks were thrust upon the continental margin for considerable distances, perhaps for several hundreds of kilometers.

In summary, all geologic evidence strongly suggests that the Talkeetna Mountains and the Chulitna district are part of a major plate-tectonic collision zone, and the resulting structural features are truly gigantic and alpine in character.

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Serpentinite bodies in the Willow Creek district, southwestern Talkeetna Mountains, Alaska

By Béla Csejtey, Jr., and Russell C. Evarts

Several small rock bodies in the Willow Creek district of the southwestern Talkeetna Mountains have been previously described in the literature as "altered mafic rocks" (Capps, 1940; Ray, 1954). Recent geologic investigations reveal that these bodies are actually serpentinite, which probably was emplaced as alpine-type serpentinite protrusions (Lockwood, 1972).

The serpentinite forms six irregularly shaped, discordant, and rather poorly exposed bodies within a terrane of pelitic mica schist of probable Jurassic age (fig. 39) (Csejtey and others, 1978). Most of these bodies are quite small, but

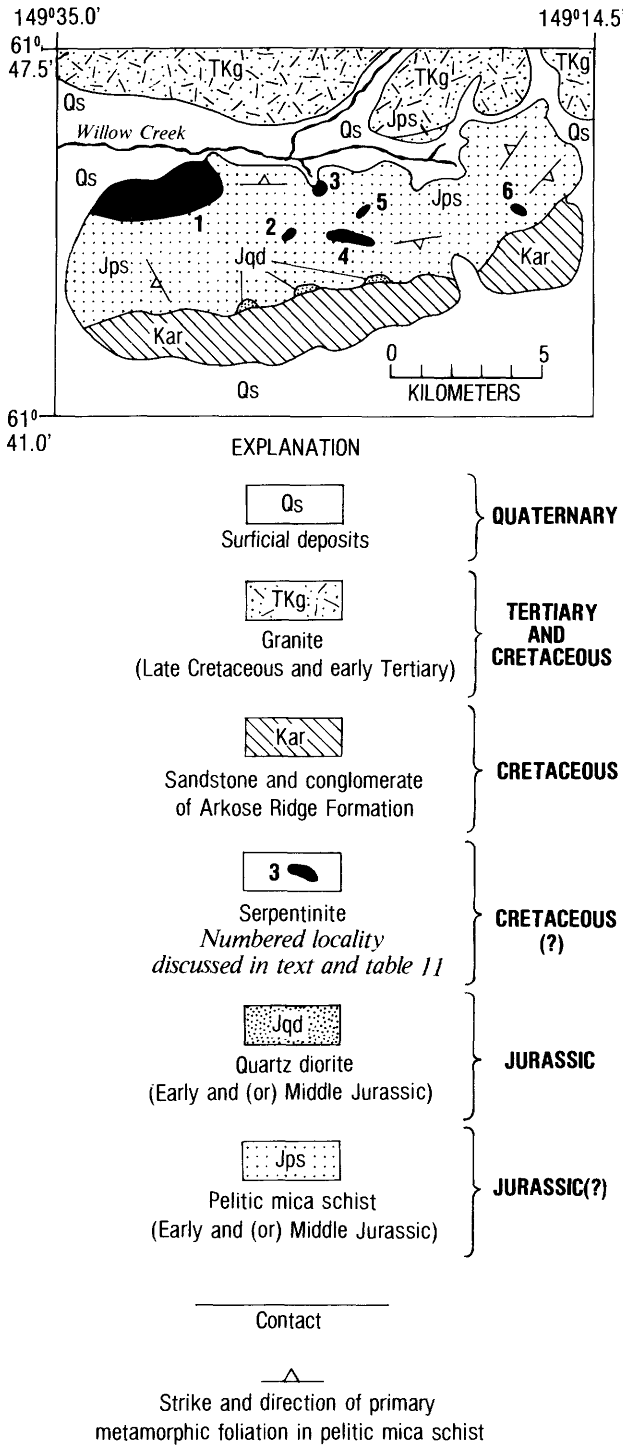

FIGURE 39.—Generalized geologic map showing location of serpentinite bodies in Willow Creek area, Talkeetna Mountains, Alaska.

the largest (no. 1 on fig. 39) is about 4.5 km long and 1.5 km wide. All of them are pervasively sheared, but the shear planes exhibit a random orientation that bears no relation to the foliation in the surrounding mica schist.

The serpentinite is medium greenish gray to black and is composed of aphanitic masses of serpentine group minerals, talc, chlorite, and minor amounts of actinolite-tremolite and undetermined opaque minerals. Relict minerals or textures were nowhere observed. Two of the serpentinite bodies (nos. 3, 4) have rims of coarse-grained actinolite which formed as a result of postemplacement metamorphic reaction with the mica schist host rock.

Fire assay analyses for platinum group elements and standard semiquantitative spectrographic analyses were obtained on representative samples from all six serpentinite bodies. The results of the fire assay analyses and the spectrographic analyses for the diagnostic elements chromium and nickel are given in table 11. The high chromium and nickel contents are characteristic of ultramafic rocks (Goles, 1967), and the concentration levels of the platinum group elements are similar to those in serpentinized alpine-type peridotites (Keith and Foster, 1973; Page and others, 1975).

The time of emplacement of the serpentinite bodies is imperfectly known. Potassium-argon age determinations on actinolite from the reaction rims of bodies 3 and 4 yielded minimum ages of 88 and 91 m.y., respectively (Csejtey and others, 1978), indicating that the bodies were in place by early Late Cretaceous time. The mica schist host rock is believed to be of Early and (or) Middle Jurassic primary metamorphic age on the basis of regional geologic considerations (Csejtey and others, 1978). Judged from their relation to the primary foliation in the mica schist, the serpentinite bodies were emplaced in post-Middle Jurassic time. In the middle and Late Cretaceous an intense, alpine-type orogeny took place in southern Alaska, including the Talkeetna Mountains (Csejtey and others, 1978). It seems likely that the emplacement of the serpentinites occurred during an early stage of this orogeny, and the reaction rims were formed when the temperature increased later in this same orogeny. Therefore, the serpentinites are assigned a Cretaceous(?) age.

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Trondhjemite in the Talkeetna Mountains, south-central Alaska

By Béla Csejtey, Jr., and W. H. Nelson

A large pluton of trondhjemite, an uncommon rock type previously not known to occur in southern Alaska, has been discovered during reconnaissance geologic mapping in the central Talkeetna Mountains. The pluton crops out in a northeast-trending body, approximately 120 km long and at most 15 km wide, roughly between the headwaters of Granite Creek (lat 61° 51′ N., long 148° 23′ W.) and the mouth of the Oshetna River (lat 62° 38′ N., long 147° 23′ W.). It appears to be epizonal and discordantly intrudes Early and Late Jurassic plutonic and metamorphic rocks. Although the trondhjemite pluton is of fairly uniform lithology, large parts of it have been sheared and saussuritized. Lithologic descriptions and a 1:250,000-scale map of the pluton and surrounding country rock are given in Csejtey and others (1978).

Typically, the unaltered trondhjemite is a light-gray, medium- to coarse-grained rock

TABLE 11.—*Semiquantitative spectrographic analyses for chromium and nickel and fire assay analyses for platinum group metals on serpentinite from the Willow Creek district, Talkeetna Mountains, Alaska*

[Map numbers shown refer to figure 40. All values given in parts per million. Looked for but not detected in any samples at the following lower limits of detection: Rh, 0.002; Ru, 0.100; and Ir, 0.050. N = not detected at the following lower limits of detection: Pt, 0.005; and Pd, 0.002. Semiquantitative spectrographic analyses by D. F. Siems and J. M. Motooka; fire assay analyses by R. R. Carlson]

Map No.	Sample No.	Cr	Ni	Pt	Pd
1	73ACy-61	5,000	2,000	N	N
	73ACy-62	2,000	1,500	N	N
	73ACy-63	3,000	150	N	N
	73ACy-81	5,000	2,000	.010	.005
2	73ACy-30	2,000	200	.030	.030
3	73ACy-17	3,000	1,000	N	N
4	73ACy-44	1,000	1,000	.010	N
	73ACy-46	5,000	1,500	.010	.005
5	73ACy-73	2,000	1,000	.030	.030
6	73ACy-40a	1,500	500	N	N

having a granitic texture. A faint flow foliation is locally developed. Major rock-forming minerals are plagioclase (oligoclase to sodic andesine), quartz, potassium feldspar (as much as 10 percent by volume), biotite, and subordinate amounts of muscovite. Opaque minerals (probably mostly hematite), sphene, and apatite are accessory. Color index ranges from three to nine. Ternary modal plots of 15 representative trondhjemite samples are shown in figure 40*A*. Seven of these samples have been chemically analyzed, and their corresponding normative mineral compositions (Q:Or:(Ab+An)), indicated by tie-lines, are also shown. Numbers adjacent to the modal plots indicate the color index.

Selected oxides and normative Or:Ab:An ratios of the chemically analyzed samples are shown in table 12. Ternary ratios of the diagnostic oxides K_2O, Na_2O, and CaO are plotted in figure 40*B*. The compositions fall within the trondhjemite field determined by Ross (1973) from the compositions of 37 trondhjemite samples from Norway, California, and Idaho. The average composition of the Talkeetna Mountains samples plots very close to the average of Ross' samples. Moreover, the normative Or:Ab:An ratios of the Talkeetna Mountains samples are very similar to the corresponding mineral ratios of Ross' samples.

Because they have more than 15 percent Al_2O_3, the Talkeetna Mountains trondhjemite samples belong to the high-Al_2O_3 trondhjemite-tonalite suite of Barker and Arth (1976). Chemical and mineralogical information so far available on the Talkeetna Mountains pluton, however, does not permit speculation as to whether the original magma was formed by fractionation of hydrous basaltic liquid or by partial melting of metabasaltic rocks, as suggested by Barker and Arth (1976).

Three potassium-argon age determinations from the north half of the pluton (Csejtey and others, 1978; Turner and Smith, 1974), including concordant ages on a mineral pair of muscovite and biotite, yielded very similar numbers, indicating the emplacement of the trondhjemite 145 to 150 m.y. ago. Thus, the trondhjemite is the youngest member of a group of Jurassic plutonic and metamorphic rocks in the Talkeetna Mountains.

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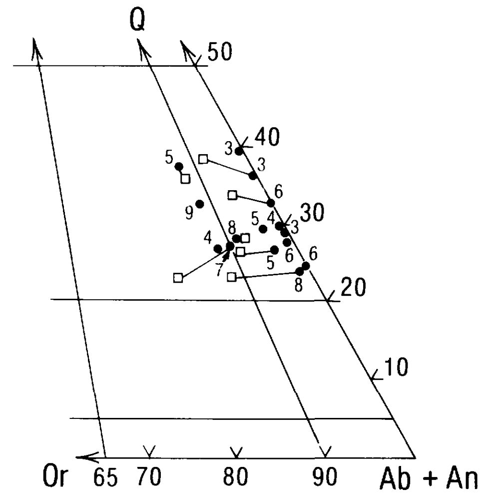
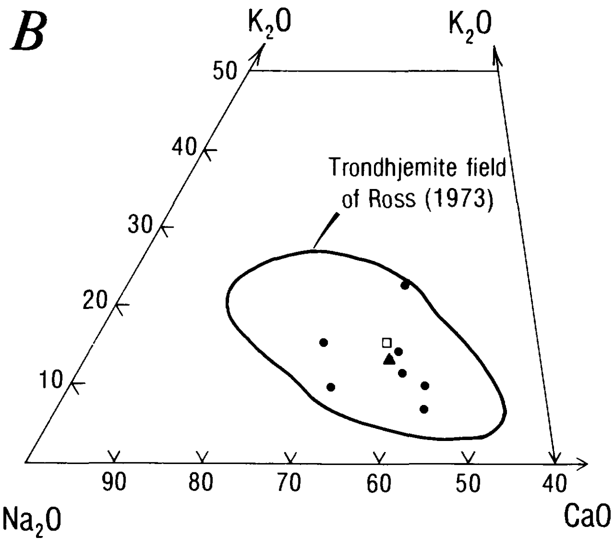
A



EXPLANATION

- 5● Mode-number indicates color index
- □ Norm [Q:Or:(Ab+An)]
- ●—□ Norm and mode of same sample indicated by tie-line

B



EXPLANATION

- ● Talkeetna Mountains sample
- ▲ Average of Talkeetna Mountains samples
- □ Average of 37 trondhjemite samples from Norway, California, and Idaho (Ross, 1973)

◄FIGURE 40.—Ternary diagrams for trondhjemite samples from Talkeetna Mountains, Alaska. *A*, Modal and normative data. *B*, K_2O:Na_2O:CaO; values shown in weight percent.

TABLE 12.—*Selected oxides, in weight percent, and ternary ratios of normative Or:Ab:An of trondhjemite samples from the Talkeetna Mountains, Alaska*

Field No.	SiO_2	K_2O	Na_2O	CaO	Al_2O_3	Or : Ab : An
73ACy-108	68.64	2.49	4.97	3.36	17.41	20.05:57.41:22.54
73ACy-114	67.38	1.50	5.38	3.69	17.64	12.23:63.06:24.70
73ACy-115	69.57	1.19	5.34	3.76	16.82	9.95:64.13:25.91
74ACy-145	74.50	.79	4.99	2.40	15.28	7.96:72.17:19.87
74ACy-146	70.20	.63	4.73	3.83	17.02	6.04:64.53:29.43
74ACy-150	68.41	1.01	5.05	4.04	17.58	8.82:63.12:28.06
74ACy-151	73.45	1.31	5.04	2.22	15.44	12.71:69.98:17.31
Average----	70.30	1.27	5.07	3.33	16.74	11.11:64.92:23.97

Mountains: Alaska Division of Geological and Geophysical Surveys Open-File Report 72, 11 p.

The ophiolite of Tangle Lakes in the southern Mount Hayes quadrangle, eastern Alaska Range: An accreted terrane?

By Warren J. Nokleberg, Nairn R. D. Albert, and Richard E. Zehner

The ultramafic rocks, mafic rocks, and weakly metamorphosed basalt, tuff, and chert in the southern part of the Mount Hayes 1:250,000-scale quadrangle may constitute an accreted ophiolite. The proposed ophiolite is well exposed near the Tangle Lakes in the Mount Hayes A–4 and A–5 1:63,360-scale quadrangles and is herein called the ophiolite of Tangle Lakes. The lower part of the ophiolite consists of the ultramafic and mafic rocks of the Fish Lake Complex of Stout (1976) (fig. 41). The upper part of the ophiolite consists of Triassic basalt, tuff, and chert of the Tangle Lakes Formation and the Boulder Creek Volcanics, named and described by Stout (1976) and lithologically correlated by him with the Nikolai Greenstone, which was described by MacKevett (1978) in the McCarthy quadrangle, to the southeast. The ophiolite is structurally underlain by the Paxson Mountain Basalt of Stout (1976).

The Fish Lake Complex occurs north of the Tangle Lakes Formation and Boulder Creek Volcanics and forms a belt about 2 km wide and 25 km long, striking west-northwest. The ultramafic and mafic rocks of the Fish Lake Complex were believed by Stout (1976) to intrude and postdate the rocks to the south of the complex because the mafic rocks of the Fish Lake Complex are very similar to the gabbro dikes that intrude the Tangle Lakes Formation and Boulder Creek Volcanics. A number of ultramafic and mafic rock units occur beneath part of the Tangle Lakes Formation along the south margin of the Amphitheater Mountains; we find these rock units are identical to the Fish Lake Complex.

The following observations, based on field and laboratory work in 1978, strongly suggest an extensive ophiolite in the southern part of the Mount Hayes quadrangle: (1) The ultramafic rocks of the Fish Lake Complex are mainly olivine and olivine-pyroxene cumulates; the overlying mafic rocks of the complex are mainly plagioclase-pyroxene cumulates. The textures are typically apposition fabrics, characteristic of cumulate rocks, rather than the randomly oriented, interlocking crystals characteristic of quickly cooled igenous rocks, or metamorphic

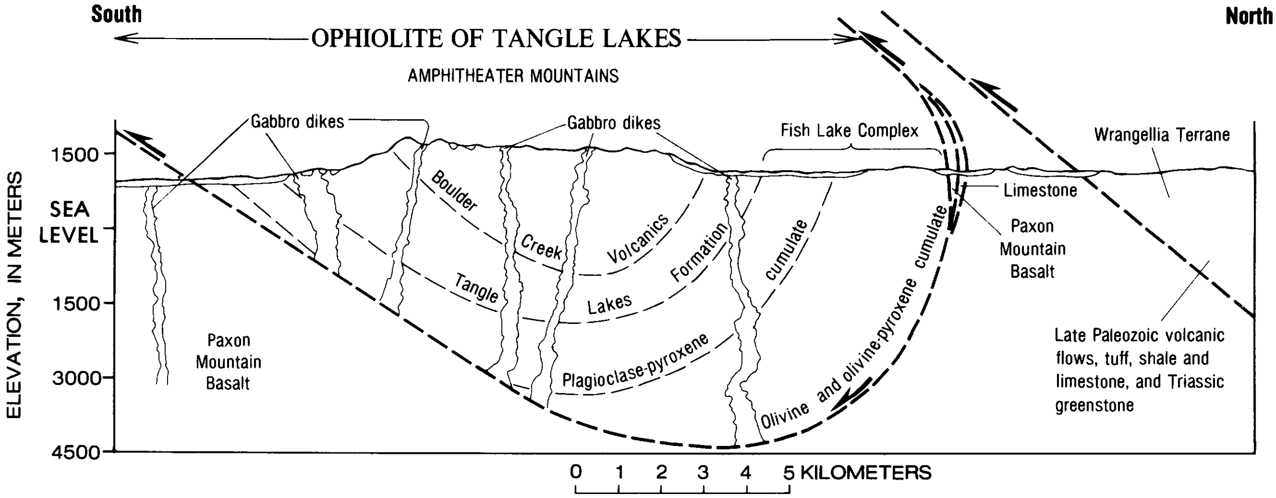


FIGURE 41.—North-south cross section through a part of Mount Hayes A–5 quadrangle showing ophiolite of Tangle Lakes. Stratigraphic nomenclature from Stout (1976).

textures characteristic of alpine peridotites and gabbros. (2) Cumulate ultramafic and mafic rock units underlie the Tangle Lakes Formation between Fielding and Fourteen Mile Lakes. (3) Intrusive gabbro dikes crosscutting the Tangle Lakes Formation and Boulder Creek Volcanics do not have the cumulate textures characteristic of the Fish Lake Complex. Instead, these finer grained dikes have hypautomorphic-granular textures characteristic of quickly cooled igneous rocks. Because of similar texture and mineralogy, the dikes may represent feeders for the basalt flows they intrude. (4) No high-temperature contact metamorphic aureole is developed adjacent to the ultramafic and mafic rocks. Instead, these rock units exhibit a pervasive, low-grade, greenschist-facies metamorphism, even near the contacts with the mafic rocks. (5) Plagioclase composition throughout the proposed ophiolite is more calcic than An_{50}. Therefore, the volcanic rocks throughout the ophiolite are of basaltic rather than andesitic composition as reported by Stout (1976). (6) Interpretation of aeromagnetic data (Alaska Division of Geological and Geophysical Surveys, 1973) indicates that partially serpentinized ultramafic and mafic rocks form a continuous unit from the Fish Lake Complex in the north to the ultramafic and mafic rock units on the south side of the Amphitheater Mountains.

Our geologic interpretation (fig. 41), along the same line as cross section A–A′ of Stout (1976), shows: (1) the conformable ophiolite sequence of the cumulate ultramafic and mafic rocks of the Fish Lake Complex, the Tangle Lakes Formation, and the Boulder Creek Volcanics; (2) younger intrusive gabbro dikes cutting all units of the ophiolite; (3) the Paxson Mountain Basalt structurally underlying the ophiolite; (4) a newly discovered tectonic breccia of Paxson Mountain Basalt and unmetamorphosed limestone and dolomite just north of the Fish Lake Complex; and (5) a major thrust fault separating the ophiolite of Tangle Lakes from the Paxson Mountain Basalt.

The ophiolite of Tangle Lakes differs markedly in stratigraphy and structure from the Nikolai Greenstone (MacKevett, 1978). The ophiolite may represent an oceanic crust base to the Wrangellia terrane which occurs to the north (D. L. Jones, oral commun., 1979), or a slice of unrelated oceanic crust accreted to the Wrangellia terrane. Current mapping shows that the ophiolite extends westward about 30 km from the Tangle Lakes. Problems with the proposed ophiolite include the absence of a sheeted dike complex between the mafic rocks and basalts and the absence of chert and shale overlying the basalts, both common features of ophiolites. Additional work is needed to test the proposed ophiolite of Tangle Lakes and more fully to define the age and origin of this interesting suite of rocks.

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Uranitite in sideritic nodules from Tertiary continental sedimentary rocks in the Healy Creek basin area, central Alaska

By Kendell A. Dickinson

Anomalous amounts of uranium in siderite-bearing Tertiary continental rocks of Alaska have been reported in the Susitna Lowlands by Dickinson and Campbell (1978) and in the Healy Creek basin area by E. W. Abbott and R. K. Dickson (unpub. data, 1978). Samples collected in the Susitna Lowlands contain as much as 79 ppm uranium, and, according to Abbott and Dickson, samples from the Healy Creek area contain as much as 1,500 ppm uranium. Commercial deposits of uranium have not yet been found in either area.

Samples consisting of several sideritic nodules and their matrix material were collected from near the base of the Healy Creek Formation along Dexter Creek (fig. 42) by R. K. Dickson and K. A. Dickinson during the summer of 1978. The mineralogy of the samples was determined by X-ray diffraction. Chemical content was determined by semiquantitative spectrographic analysis, and the uranium content was obtained by the delayed-neutron method. The chemical analyses were done in the analytical laboratories of the U.S. Geological Survey at Denver. The spectrographic analyses were done by M. J. Malcolm and the neutron-activation analyses by H. T. Millard and others. Autoradiographs and photographs were made from sawed slabs of the nodules. The autoradiographs were prepared by J. R. Dooley, Jr., and are of a type termed radioluxographs (Dooley, 1958).

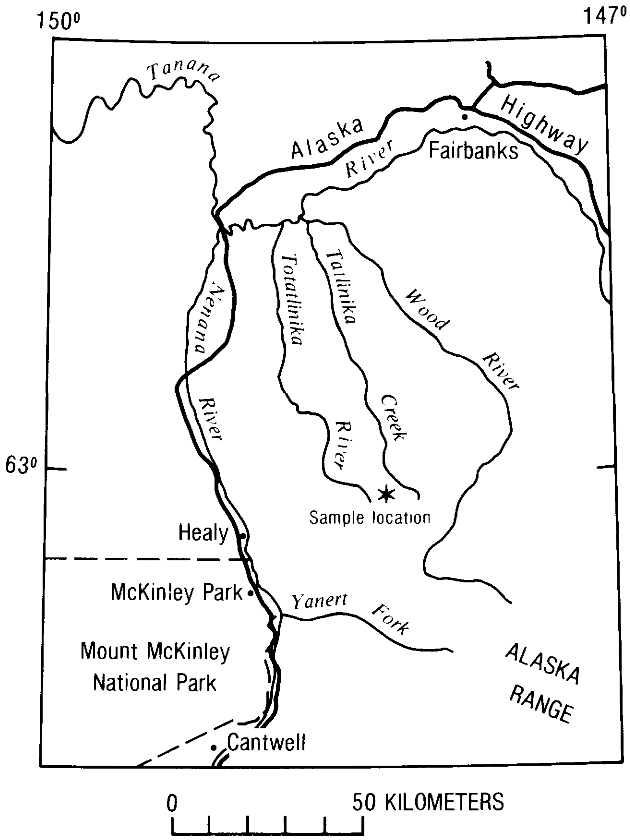

FIGURE 42.—Map of part of central Alaska showing sample location.

The samples were collected from the Oligocene and Miocene Healy Creek Formation about 3 m above its base where it overlies the Mississippian(?) Totatlanika Schist. The Healy Creek Formation consists of a very clayey gray to light-reddish-brown conglomeratic sandstone containing carbonized plant detritus.

The nodules are irregularly shaped to roughly spherical and are 2–5 cm in diameter. They consist of an outer reddish-brown rind about 3 mm thick and a yellowish-brown core. They contain dense gray areas that cut across the red-yellow color boundary. The nodules contain siderite, kaolinite, quartz, goethite, manganite, and uranitite. Siderite is the predominant mineral in the central yellowish-brown parts; goethite is found mainly in the outer rind, and uranitite is in the randomly scattered gray areas that appear dense on the photographs (fig. 43*B* and *D*) and light-colored on the autoradiographs (fig. 43*A* and *C*). The matrix sample consisted almost entirely of quartz and kaolinite, although a small amount of feldspar was detected. A composite sample of nodules contained 717 ppm uranium, and the matrix sample contained 54 ppm uranium. The composite nodule sample contained 3,000 ppm manganese, and the matrix sample contained 200 ppm.

The nodules were formed after deposition of the Healy Creek Formation, and the uranium was deposited at a still later stage. The presence of siderite and manganite in the nodules suggests alkaline depositional conditions at the time of nodule formation. In addition, the siderite is evidence of a reducing diagenetic environment. The goethitic outer rind was produced later when oxidizing solutions came in contact with the nodules. The uranium probably also came in later with the oxidizing solutions and was precipitated by remnants of reducing environment that persisted within the siderite.

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Watana and Devils Canyon damsites, Susitna River, Alaska

By Reuben Kachadoorian and H. J. Moore

The feasibility of constructing two dams on the Susitna River, Alaska, is currently under evaluation by the U.S. Army Corps of Engineers. These dams have been proposed for the purpose of developing the hydroelectric power potential of the Susitna River; one locality is at Devils (fig. 44). The proposed Devils Canyon site is located about 29 km upstream from the Gold Canyon, and the other is at the Watana site

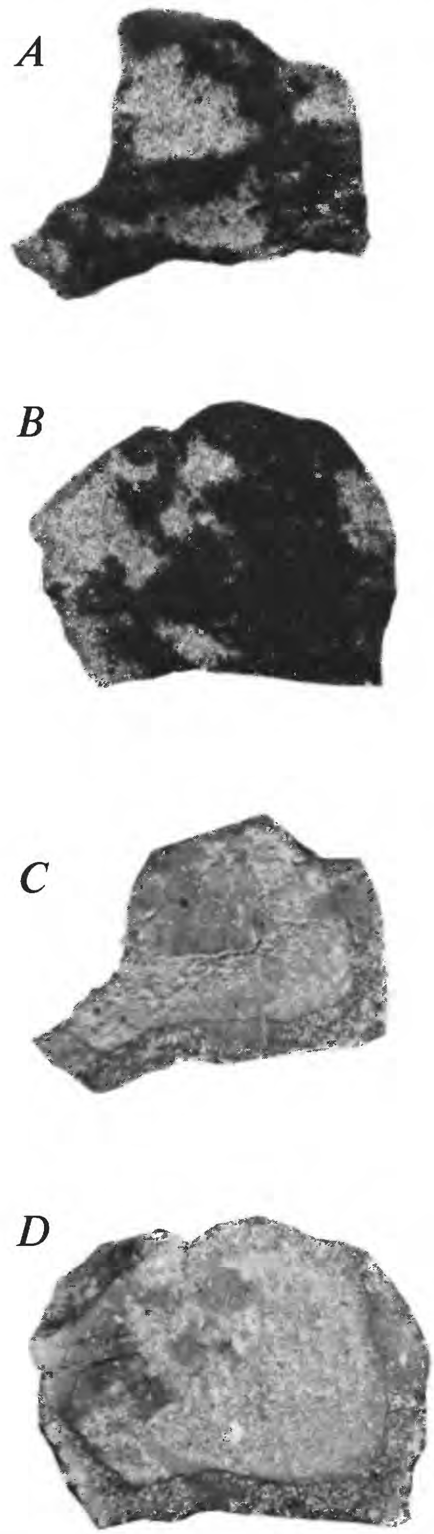

FIGURE 43.—Sawed slabs (actual size) of a uranium-bearing sideritic nodule from Healy Creek basin. *A* and *B*, Radioluxographs. Light areas show parts containing uraninite. *C* and *D*, Photographs. Uranite visible as dark areas; darker grainy areas are reddish-brown outer rind, containing goethite; lighter grainy areas are yellowish-brown inner part of nodule, containing siderite.

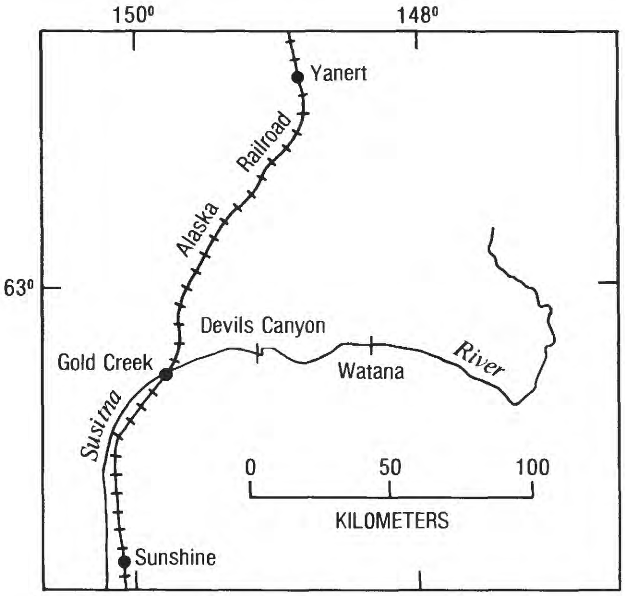

FIGURE 44.—Locations of proposed Watana and Devils Canyon damsites.

Creek Station on the Alaska Railroad. This dam would be 194 m high; the reservoir formed would have a water altitude of 442 m above sea level and would extend upstream 45 km to the proposed Watana damsite. The height of the proposed Watana dam would be 247 m; the reservoir would have a maximum water altitude of 671 m and would extend upstream 87 km. The total power produced by both dams would be about 600 MW (megawatts)—approximately 270 MW at Devils Canyon and the remaining 330 MW at Watana.

The preliminary evaluation of the proposed damsites and their reservoirs includes a study of active faults, seismic activity, potential and recent landslides, and other potential geologic hazards. The U.S. Army Corps of Engineers requested that the U.S. Geological Survey make a study of these hazards. Accordingly, the authors made a reconnaissance geologic study of the Watana-Devils Canyon area between July 25 and August 7, 1978. Fieldwork was accomplished using a helicopter, which was shared with Corps of Engineers personnel who were conducting detailed studies at the proposed Watana damsite.

The geology of the Watana-Devils Canyon area is rather complex (Csejtey and others, 1978). Bedrock consists chiefly of tightly folded, metamorphosed, and faulted volcanic and sedimentary sequences that range in age from late Paleozoic to Late Cretaceous and have been intruded by Late Cretaceous and early Tertiary granodiorite (55 to 75 m.y.). These rocks are overlain by Tertiary volcanic and sedimentary rocks (about 50 to 58 m.y.). Sedimentary rocks, of possible late Oligocene age (about 25 m.y.; J. A. Wolfe, written commun., 1977), are exposed in Watana Creek about 7 km upstream of its confluence with the Susitna River. These strata are gently tilted and possibly faulted.

Glacial drift of late Wisconsinan age (10,000–25,000 years ago) covers much of the Watana-Devils Canyon area. These late Wisconsinan glacial sediments consist of till of ground, lateral, and end moraines as well as esker and outwash gravel. The glacial sediments, in turn, have been and continue to be eroded and modified by fluvial erosion and mass wasting processes. Some of the results of these processes are V-shaped valleys, flood plains and terraces, solifluction lobes and terraces, slumps, landslides, and talus cones.

The late Wisconsinan glaciation covered the sites of the Watana and Devils Canyon dams and reservoirs. Kachadoorian (1974) reported that at Devils Canyon the Susitna River occupies the same channel at the present time as it did prior to the Wisconsinan glaciation. The presence of eskers and other glacial debris on the floor of the Susitna River Canyon upstream from the Watana damsite shows that the river has accomplished no major downcutting in the canyon since retreat of the late Wisconsinan glacier.

Our geologic reconnaissance of faults in the Watana-Devils Canyon area verified those reported by Csejtey and others (1978). No evidence for recent or active faulting was observed along the traces of any of the known or inferred faults. Recent movement of surficial deposits has occurred, but only as the result of gravity soil failure slumps that left scarps as the surficial material moved downslope. Some of this recent slumping may have been caused by seismic shaking and by minor displacements of bedrock along joints. A comparison of the first-order leveling surveys in 1922 and 1965 along the Alaska Railroad between Sunshine and Yanert indicates that the surface has tilted; the south side has moved downward 0.3 m. This tilting probably occurred during the Alaska earthquake of 1964.

Landsliding into the Susitna River has occurred in the past, and future landsliding appears probable. Additionally, on steep slopes at altitudes below the proposed reservoir water levels, poorly consolidated Tertiary sediments, glacial debris, and alluvium may slump and slide into the reservoirs, especially at the Watana Dam reservoir. Some of these sediments contain permafrost that may be ice rich, which increases the probability of slumping when they are thawed by water impounded behind the dams.

The proposed Devils Canyon and Watana dams are located in a region of high seismicity. The tectonic framework of the region is not well understood because of the lack of local seismic monitoring stations. Our present knowledge of the region indicates that hypocenters of earthquakes range from less than 10 km to greater than 175 km deep in the region of the proposed dams. At this time we are unable to predict reliably the locations, magnitudes, and frequencies of future earthquakes that could affect the proposed structures.

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Clay model showing deformation of the Wrangell Mountains along gravity-correlative Landsat lineaments in the McCarthy quadrangle, Alaska

By Nairn R. D. Albert and Wm. Clinton Steele

Several lineaments observed on Landsat imagery of the McCarthy quadrangle, Alaska (Albert and Steele, 1976) spatially correlate with gravimetric data (Barnes and Morin, 1976). Because these gravimetric data mostly reflect deep, regional features, such as changes in type and thickness of crust, these lineaments are likely to be deep, fundamental features such as fractures, or zones of weakness, which penetrate the crust and probably have played a role in the orogenic history of the Wrangell Mountains in the McCarthy quadrangle.

To determine the response of the features represented by the lineaments to uplift, a clay model of the quadrangle was constructed and deformed. A single layer of clay, approximately 13 mm thick, was rolled out to cover the McCarthy 1:250,000-scale topographic sheet. The model was then cut according to the lineaments that seem to correspond most closely to gravimetric data. Cuts were made for the entire lengths of the lineaments even though most correspond to gravimetric data along only part of their lengths. The clay model was then deformed by uplifting along the axis of the profound gravity low related to the Wrangell Mountains.

The lineament cuts responded to the deformation in one of three ways: 1) tension, 2) compression, and 3) no change. Tensional lineaments are those along which blocks on either side diverge along their upper surfaces; compressional lineaments are those along which the blocks converge. The resulting configuration of the clay model closely resembles a generalization of the topography of the Wrangell Mountains (fig. 45). Five of the six volcanoes in the quadrangle lie directly upon or very close to tensional lineaments. Furthermore, the Kennecott-type copper deposits are mainly grouped near compressional lineaments.

The Kennecott-type copper mineralization in the McCarthy quadrangle is complex and poorly understood. The more popular theories on its origin tend to preclude obvious control by

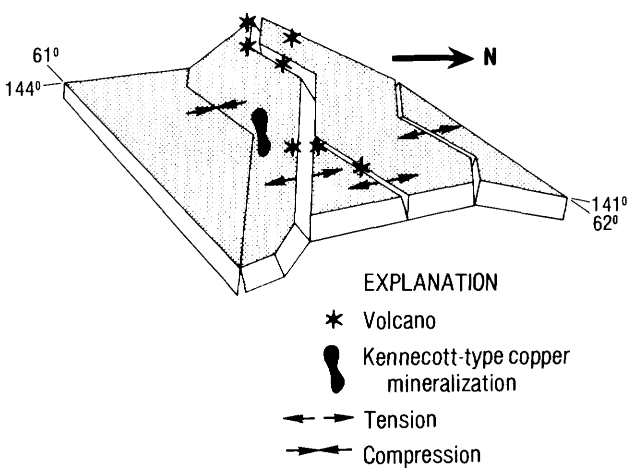

FIGURE 45.—Oblique view of deformed clay model of McCarthy quadrangle.

fracture systems or zones of weakness which the lineaments may represent (Armstrong and MacKevett, 1977). Nevertheless, results of the model studies strongly suggest that several lineaments observed in Landsat imagery are related to geologic features and events in the McCarthy quadrangle which may have had a significant, although obscure, influence on the concentration of minerals, particularly copper.

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The Border Ranges fault in the Saint Elias Mountains

By George Plafker and R. B. Cambell[7]

Geologic mapping by the Geological Survey of Canada and U.S. Geological Survey has provided new data on the location and geologic relations of the Border Ranges fault in the rugged and remote Saint Elias Mountains (Campbell and Dodds, 1978, 1979; Plafker and Hudson, unpub. data, 1975–79). The fault is a major tectonic boundary in southern Alaska that defines the landward margin of an oceanic accretionary terrane of Mesozoic age (MacKevett and Plafker, 1974; Plafker and others, 1977; Berg and others, 1978).

The Border Ranges fault is discontinuously exposed in the Saint Elias Mountains north of the Alsek River as a vertical to north-dipping thrust zone (fig. 46). Elsewhere, the trace is largely beneath ice, snow, water, and alluvium, so that its position is known primarily by fault-juxtaposed terranes that differ markedly in lithology, structure, and age. The probable position of the fault from Tarr Inlet to Cross Sound in Glacier Bay National Monument is along the southwestern margin of a belt of upper Paleozoic(?) metamorphic rocks described by Brew and Morrell (1978) as the Tarr Inlet suture zone.

The area north of the fault consists of two geologically distinctive, structurally juxtaposed terranes characterized by diverse assemblages of metasedimentary and metavolcanic rocks extensively intruded by late Paleozoic, Mesozoic, and Tertiary plutonic rocks as well as by dike complexes of intermediate to felsic composition (Berg and others, 1978; Brew and others, 1978; Campbell and Dodds, 1978, 1979; Hudson, Plafker, and Lanphere, 1977; Hudson, Plafker, and Turner, 1977). The older terrane (Alexander terrane), which is juxtaposed along the fault for about 10 km in the Art Lewis Glacier drainage and possibly for 15 km in the upper Seward Glacier area, includes rocks ranging in age from early to late Paleozoic. The younger terrane (Wrangellia?), which is adjacent to the Border Ranges fault on the north elsewhere in the Saint Elias Mountains, is characterized by bedded rocks of late Paleozoic to Late Triassic age. The country rocks are intruded by large, foliated tonalite and granodiorite plutons of Jurassic and Jurassic and Cretaceous age and smaller intrusive bodies of Tertiary age. The upper-plate rocks, in general, are increasingly metamorphosed and schistose toward the fault, where they commonly are tightly folded about steeply dipping axial planes.

The lower plate, south of the fault, is dominated by a highly deformed and variably metamorphosed sequence of flysch and subordinate mafic volcanic rocks that contains numerous small plutonic bodies, dikes, and sills. The sequence is bordered on the south by mafic volcanic rocks that crop out in a remarkably continuous belt generally less than 7 km wide which traverses the length of the Saint Elias Mountains (fig. 46). The mafic rocks of this continuous southern belt are inferred to be overthrust by the metasedimentary sequence in part of the upper Seward Icefield (Campbell and Dodds, 1978), but elsewhere the two units commonly exhibit depositional and interfingering contact relations. Metamorphic gradients vary markedly both along and across the structural grain of the terrane from low-grade slaty

[7] Geological Survey of Canada, Vancouver, B.C.

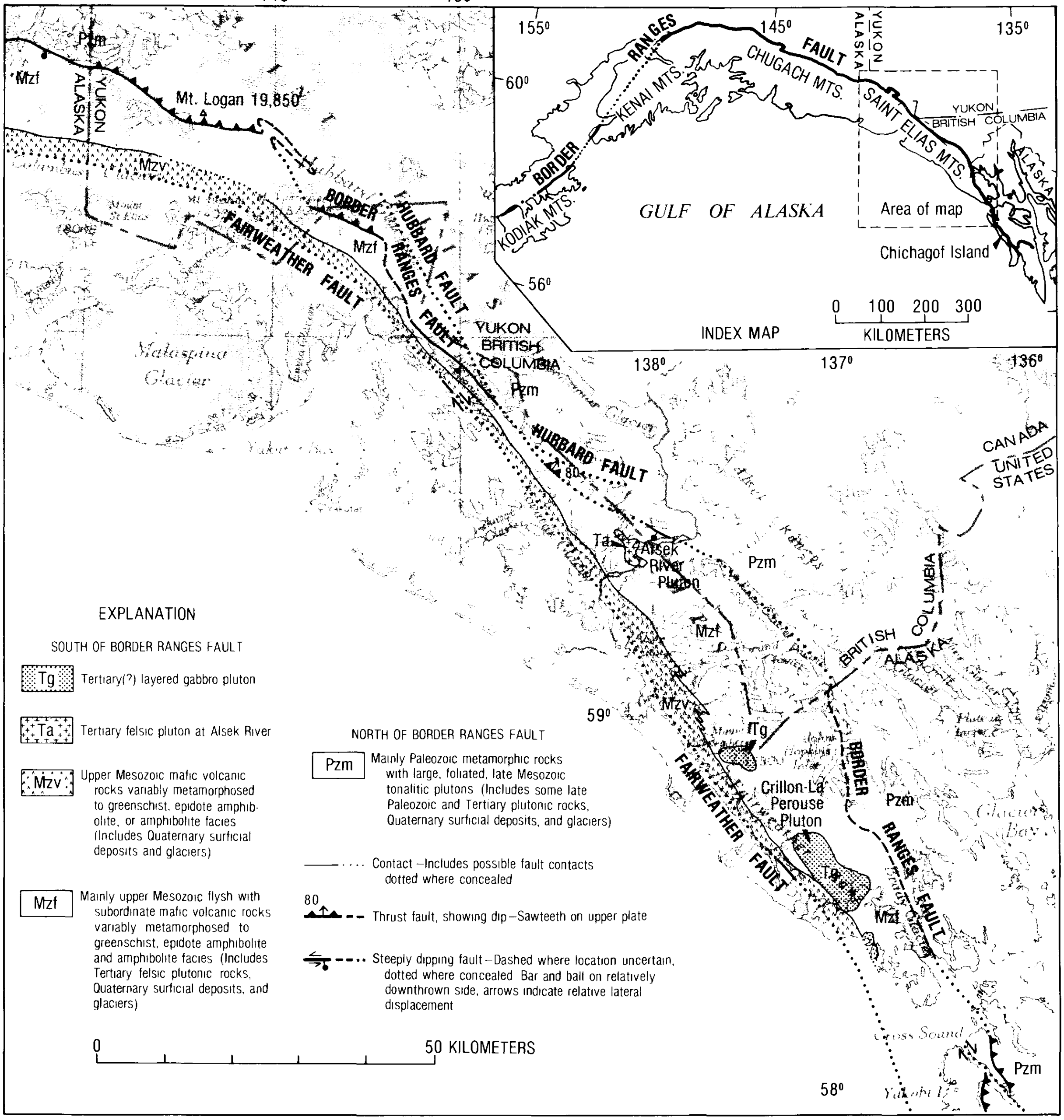

FIGURE 46.—Generalized geologic map showing location and extent of Border Ranges fault and other major structures in Saint Elias Mountains.

argillite, semischist, and greenstone to amphibolite facies schist and gneiss. The rocks are commonly isoclinally folded about steep axial planes.

A late Mesozoic, probably Cretaceous, age for the lower plate country rocks is indicated by continuity northwestward along strike with the Upper Cretaceous Valdez Group in the Chugach Mountains (MacKevett and Plafker, 1974; George Plafker, Travis Hudson, and E. M. MacKevett, Jr., unpub. data, 1973, 1974) and southeastward with the flysch and melange that is largely, or entirely, of Cretaceous age on Yakobi, Chicagof, and Baranof Islands (Plafker and others, 1977). Calcareous sedimentary rocks containing Cretaceous *Buchia* that occur near the Border Ranges fault in a structurally complex area east of Mount Logan may correlate with the flysch sequence (Campbell and Dodds, 1979; Sharp and Rigsby, 1956). However, there are significant lithologic differences between the fossiliferous sequence and the flysch, and details of their structural relations remain to be resolved.

Intrusive rocks in the Cretaceous metamorphic sequence include widespread small stocks, sills, and dikes of felsic rocks and large layered gabbro plutons in the Fairweather Range. Felsic plutonic rocks that have been reliably dated are of Tertiary age (Hudson, Plafker, and Lanphere, 1977). These rocks include the Alsek River pluton, which, owning to an analytical error, was reported to be 165 ± 5 m.y. old by Hudson, Plafker, and Lanphere but is now known to be 22 m.y. old (Marvin Lanphere, written commun., March 1, 1979). The incorrect 165-m.y. age of the Alsek River pluton was the primary rationale for previously assigning the enclosing metamorphic rocks a pre-Jurassic and probable late Paleozoic age (Hudson, Plafker, and Turner, 1977) and for the erroneous correlation of the Border Ranges fault with the Fairweather fault in the Saint Elias Mountains (Plafker and others, 1976).

The layered mafic plutons of the Fairweather Range in the southern part of the Saint Elias Mountains in Glacier Bay National Monument are predominantly pyroxene gabbro and clinopyroxene-olivine gabbro complexes, with local cumulate ultramafic zones, that are emplaced in the sequence of metamorphosed flysch and mafic volcanic rocks. Because regional relations with coextensive rocks to the northwest in the Saint Elias Range and to the southeast on Chicagof Island indicate a probable Cretaceous age for the metamorphic rocks, a latest Cretaceous or Tertiary age is indicated for the gabbro complexes. These data preclude recent interpretations to the effect that the layered gabbro and schistose country rocks are of "probable" or "unknown but inferred" Precambrian or early Paleozoic age (Brew and others, 1977; Brew and Morrell, 1978).

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Seismicity in southern and southeastern Alaska

By Christopher Stephens and John C. Lahr

The determination of earthquake parameters for events occurring in southern and southeastern Alaska has been completed for the periods October–December 1977 (Fogleman and others, 1979) and January–March 1978 (Stephens and others, 1979). Analysis of similar data for the period September–December 1978 (J. C. Lahr and Christopher Stephens, unpub. data, 1978) is also nearly complete. Epicenters for the earthquakes that occurred during the first quarter of 1978 are shown in figure 47*A*. The distribution of epicenters on this map is representative of those found for previous quarters. The apparently higher level of seismic activity east of about 145° W. is due to the emphasis we have placed on studying the seismicity of the eastern part of the network. To illustrate this bias, the earthquake data from the same time period, but with magnitudes restricted to 3.5 and greater, are replotted in figure 47*B*. Nearly all of the larger magnitude earthquakes occurred west of about 145° W.

Within the eastern part of the network all of the well-located earthquakes occur at shallow depths (less than about 35 km). Most of the activity is concentrated about 100 km northeast of Kayak Island and in a zone extending northeast of Icy Bay. A comparison of USGS data for the last quarter of 1977 and the first quarter of 1978 suggests a small but significant increase of seismic activity concentrated near Icy Bay over this time period. Data for the latter part of 1978 also indicate a slight increase in the number of earthquakes occurring near Yakutat Bay. Magnitudes of the eastern earthquakes continue to be generally less than about 3.5.

Within the eastern part of the network, several linear trends stand out against the otherwise diffused distribution of earthquake epicenters. These features can be recognized on a map that includes available USGS data for the better located earthquakes that occurred since September 1974 (fig. 47*C*). The most striking examples are one trend that extends northward from Icy Bay and a second northeast-trending alinement located about 25 km northwest of Yakutat Bay. Both of these features cut across the trends of mapped faults in the area. All earthquake epicenters from this area are currently being recalculated in an attempt to determine whether or not these or other linear features represent alinements of epicenters along particular faults.

Note:—This report was written a few days

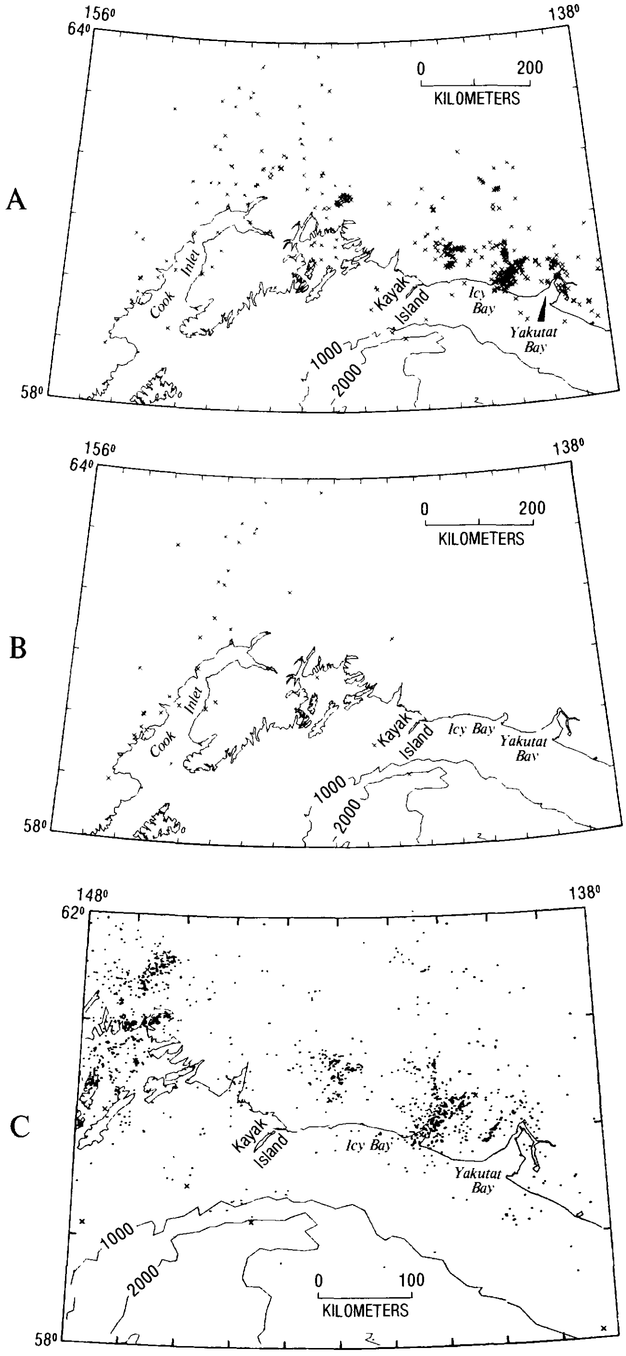

FIGURE 47.—Earthquake epicenters, southern Alaska. *A*, Epicenters of earthquakes located by USGS seismic network in southern Alaska during January–March 1978. Isobaths in fathoms. *B*, Epicenters of earthquakes with magnitudes greater than 3.5 as determined by USGS seismic network in southern Alaska during January–March 1978. *C*, Map of available better quality USGS data for epicenters of earthquakes that occurred in southeastern Alaska between September 1974 and October 1978. X's represent events greater than or equal to magnitude 3.5; dots, less than 3.5.

prior to the occurrence of the magnitude 7.7 (M_s) (Waverly Person, oral commun., March 1979) earthquake on February 28, 1979, in southeastern Alaska.

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Sources of water for a confined aquifer system at Anchorage

By Geoffrey Freethey

Development and calibration of a two dimensional finite difference model of the confined aquifer system underlying Anchorage indicates that the largest source of recharge is a narrow region along the foothills of the Chugach Mountains. However, vertical exchange of ground water through the less permeable layers separating the confined and unconfined aquifers is significant in terms of the overall ground-water budget. Withdrawal of water from the confined aquifer increases leakage downward through the confining layers and increases the contribution from this source from approximately 20 percent under steady-state conditions to 35 percent when pumped. As expected, pumping also decreases the nonpumping outflow from the system by about 30 percent. Ground water contributed from water stored in the aquifer or confining bed is negligible.

Stability of Columbia Glacier, Alaska

By M. F. Meier, L. R. Mayo, Austin Post, W. G. Sikonia, and D. C. Trabant

The discovery that Columbia Glacier may become unstable and retreat rapidly, causing an increase in the calving of icebergs, was reported by Post (1975). A program was then begun by the Columbia Glacier Team (Meier and others, 1978) to determine the glacier's stability and to predict its future behavior. Hydrographic soundings showed that this glacier, like other stable calving glaciers, terminates against a compact moraine that forms a shoal. Water depths over this shoal do not exceed 23 m at low tide. Seventeen new geodetic survey stations were established, and new survey procedures were devised to tie together a 38-station net and to survey stakes that were placed on the glacier. A new method was devised using aerial photography to map the surface ice velocity, strain rate, and acceleration field on the lower glacier. An airborne, radio-echo sounding system was developed to measure ice thickness. Estimates of ice thickness, velocity, and discharge were used in preliminary one-dimensional numerical models. The preliminary data show that the present ice thickness is not a steady-state distribution. A simple stability model for the terminus was devised, and development of more complex and realistic models was begun.

Surface ice velocity, thickness change, and snow and ice balance were measured at 57 sites, and glacier thickness was measured by surface radar at 35 sites throughout the 1,100 km^2 of Columbia Glacier by L. R. Mayo (USGS), D. C. Trabant (USGS), Rod March (University of Alaska), and Wilfried Haeberli (Federal Institute of Technology, Zürich). At the highest site, 2,540 m above sea level and 65 km from the terminus, 10 m of snow (5.2 m water equivalent) accumulated during the 1977 measurement year; little melting and almost no liquid precipitation occurred. Surface velocity measured at this station was only 88 m/yr, and the ice thickness was 760 m. At the average equilibrium line (approximately 700 m altitude) the ice was nearly 1,000 m thick, and surface velocity near the centerline ranged from 600 to more than 1,000 m/yr. In this area, 37 km from the terminus, the bottom of the ice is near or below sea level. Should drastic retreat begin, the newly exposed fiord could extend as far inland as the present equilibrium zone of the glacier.

The lowest stake on the flow centerline was 5 km from the calving face at about 200 m altitude. The ice thickness at this point was about 600 m and the surface velocity was 900 m/yr. A net 5.4 m of ice was lost owing to ablation, but nonequilibrium ice flux through this area resulted in a surface lowering of 8.6 m.

A detailed bathymetric map was compiled by the U.S. Geological Survey RV *Growler* during the spring and summer of 1977 (Post, 1978) because very few bathymetric data were available for the area. Large quantities of glacier ice in the form of brash and small- to medium-size icebergs (as much as 100 m long) were discharged from Columbia Glacier, especially during summer and fall months. The rate of discharge fluctuated greatly from day to day. Iceberg frequency was greatest in Columbia Bay and the waters north of Glacier Island, which, on occasion, were so encumbered with ice as to render the area inaccessible to shipping. Less frequently, dangerous bergs drifted into Prince William Sound east and west of Glacier Island.

Analysis of periodic aerial photography by W. G. Sikonia and Austin Post has provided data on seasonal changes in the terminal position, thickness, and flow of Columbia Glacier. Very large embayments in the glacier front formed during the summer and fall of 1975, 1976, 1977, and 1978, and by January 1979 the glacier had retreated from Heather Island, on which it had terminated since at least 1850. Largely owing to ice loss by embayment formation, the glacier area was reduced by more than 1 km^2 between July 27, 1974, and January 6, 1979. Embayment formation resulted from localized rapid iceberg calving; the calving rate correlated well with the runoff rate. Glacier flow varied seasonally and synchronously over at least the lower 17 km of the glacier; superimposed on this seasonal variation were large accelerations in the flow near the terminus after embayment formation. Surface speed near the centerline at about 5 km from the terminus increased from an average of 1.9 m/day, during 1965 to 1967, to 2.6 ± 0.1 m/day between 1977 and 1978. In the lowest 15 km of the glacier, the average surface level was lowered about 9 m between 1957 and 1974, but from 1974 to 1978 the average lowering was about 13 m (fig. 48). These data demonstrate that the lower glacier was reduced in mass both by retreat and thinning and had not been fully compensated by more rapid flow of ice from the upper glacier. These losses are the greatest yet recorded for Columbia Glacier.

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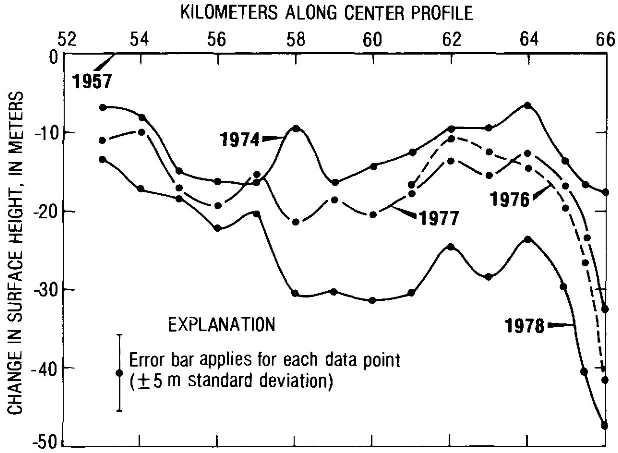

FIGURE 48.—Change in surface height of Columbia Glacier from 1957 to 1978.

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SOUTHEASTERN ALASKA

Late Triassic fossils from a sequence of volcanic and sedimentary rocks on the Chilkat Peninsula, southeastern Alaska

By George Plafker, Travis Hudson, and N. J. Silberling

The Chilkat Peninsula, located at the head of Lynn Canal just south of Haines, is underlain by a bedded sequence of mafic volcanic and sedimentary rocks. Mafic to ultramafic rocks intrude the volcanic sequence at the north end of the peninsula. Although the area is easily accessible and has been visited by numerous workers, no direct evidence for the age of the bedded rock sequence has been reported previously, and ages ranging from Paleozoic to Tertiary have been postulated (Buddington and Chapin, 1929; E. C. Robertson, unpub. data, 1959; D. A. Brew, oral commun., June 1978).

While studying the Dalton fault segment of the Denali fault system, Plafker and Hudson collected age-diagnostic marine megafossils at the two localities shown on figure 49. The fossil collections are from thin limestones that occur between pillow flows near the top of the volcanic unit that underlies most of the Chilkat Peninsula and from within the thinly bedded calcareous to argillaceous sedimentary sequence that is exposed southwest of the volcanic unit.

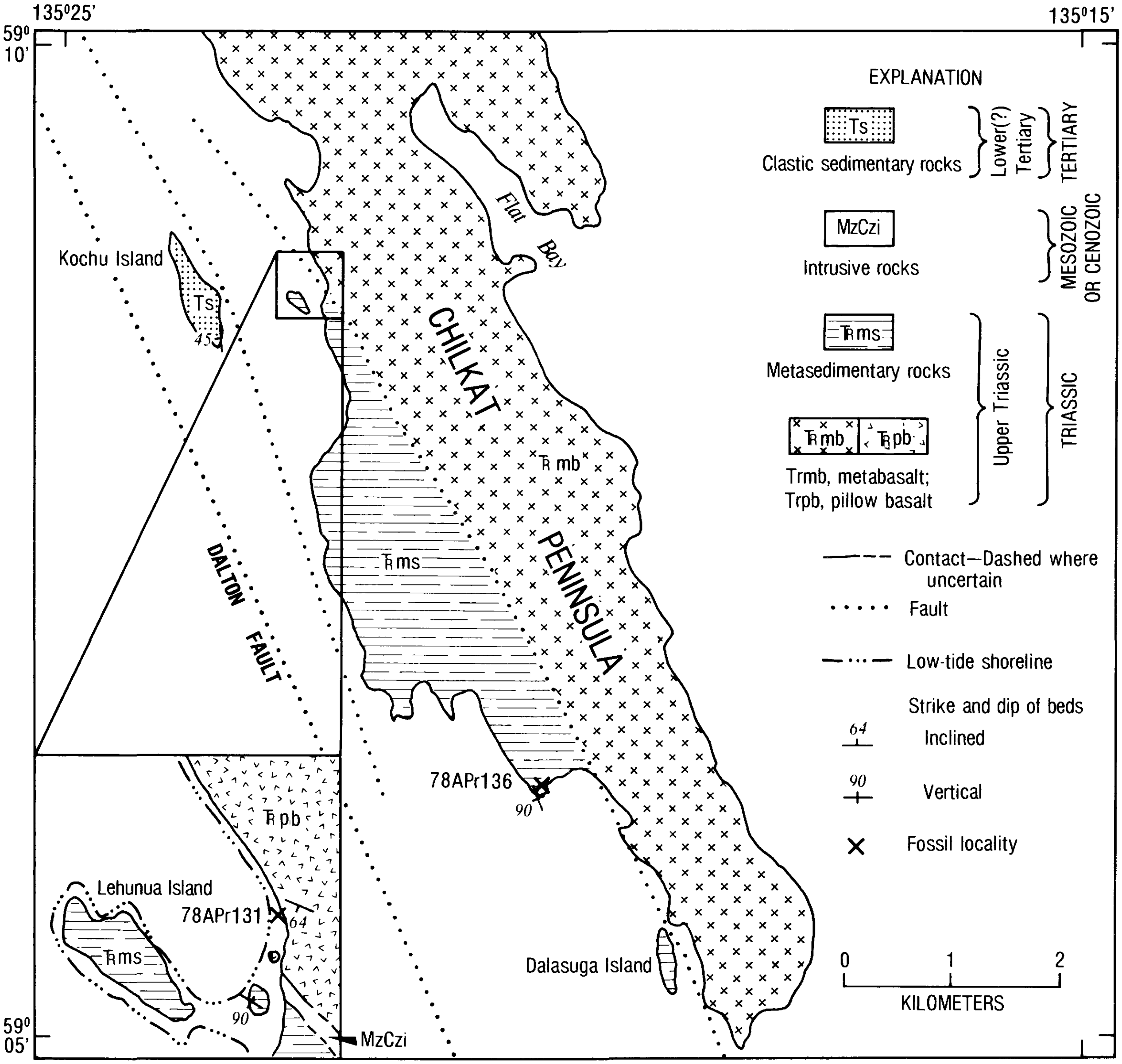

FIGURE 49.—Geologic map of Chilkat Peninsula showing locations of Triassic fossil collections 78APr131 and 78APr136.

These bedded rocks have steep to vertical dips and strike generally north-northwest parallel to the topographic trends. Facing directions observed near the contact between the volcanic and sedimentary units are to the southwest, placing the volcanic unit stratigraphically below the sedimentary unit. The contact between the volcanic and sedimentary units near fossil locality 78APr131 (fig. 49) is marked by a tonalite or granodiorite dike or sill about 10 m wide that forms a narrow ridge extending inland from the beach. The margins of the intrusion are sheared, and the sense of slip is subhorizontal and dextral. Because the shearing is restricted to mostly narrow zones along the contact of the intrusion, they are not surfaces along which large displacements have occurred.

The volcanic unit is mainly amygdaloidal basalt and greenstone. At fossil locality 78APr131 (fig. 49), the unit consists of vesicular and amygdaloidal flows 1 m or more in thickness that have well-preserved pillow forms and distinct rims of very finegrained devitrified glass.

At this locality fossiliferous limestone occurs in the volcanic unit as discrete beds or discontinuous lenses, as much as about 90 cm thick, within a few meters of the top of the volcanic unit. Much of the fossiliferous rock is a gray to dark-gray coquina with common nodular to layered black chert and abundant fragments of devitrified glass. A variety of well-preserved ammonites, belemnites, and clams was found *in situ* and in beach float. Petrographic analysis of samples of the carbonate rocks by A. K. Armstrong (written commun., Feb. 13, 1979) indicates that they may be classified as ostracode-pelecypod wackestone and pelecypod-devitrified glass packstone. Although shearing is common, the rock shows no evidence of thermal or stress metamorphism.

The sedimentary unit on the Chilkat Peninsula includes thinly interbedded argillaceous and calcareous rocks with subordinate fine- to very fine-grained sandstone. At locality 78APr136 (fig. 49) a distinctive section about 20 m thick of interbedded brick-red to greenish-gray calcareous shale and sandstone contrasts with the usual gray colors of the sedimentary unit. Bedding is rhythmic, and primary sedimentary structures are locally perfectly preserved.

At locality 78APr136 pelecypod, ammonite, and other fossil fragments occur in a sandy coquina bed about 60 cm thick within the sedimentary sequence. In thin section the rock is characterized as unrecrystallized pelecypod-ostracode-echinoderm wackestone to packstone (A. K. Armstrong, written commun., Feb. 13, 1979). Lithologically, the rock is identical to the fossiliferous limestone within the pillow flows except that large megafossils are less abundant and chert is absent.

Collection 78APr131 contains well-preserved fossils including the ammonites *Hoplotropites* cf. *H. jokelyi* (Hauer), *Thisbites* aff. *T. agricolae* Mojsisovics, and ?*Sandlingites* sp. and the bivalves *Halobia* cf. *H. rugosa* Guembel and *H.* cf. *H. cordillerana* Smith. In North America the genus *Hoplotropites* is restricted to rocks of late Karnian age, and the other kinds of ammonites and bivalves in the collection could also be of this age. Fossil collection 78APr136 contains poorly preserved and partial specimens of juvavitinid, arcestid, and probable tropitid ammonites and unidentified bivalves of Late Triassic, probably late Karnian age.

Our new data suggest the following interpretations: (1) The Chilkat Peninsula bedded sequence is partly, if not entirely, of Triassic age. The section bracketed by the fossil localities spans the contact between the volcanic and sedimentary units and is of Late Triassic and probable late Karnian age. (2) The belt of Triassic rocks on Chilkat Peninsula probably continues 135 km northwestward into adjacent parts of British Columbia, where possibly correlative pillow basalts have been described in the Squaw Creek-Rainy Hollow area (Watson, 1948). In this area the postulated continuation of the Chilkat Peninsula Triassic sequence is apparently terminated against the Dalton segment of the Denali fault system. (3) The Chilkat Peninsula Triassic rocks are included in the Taku terrane, a linear tectonostratigraphic belt that extends 650 km through southeastern Alaska (Berg and others, 1978). (4) The general lithologic sequence and age of the Chilkat Peninsula rocks can be compared to those of the Nikolai Greenstone and overlying Chitistone Limestone, which characterize parts of another tectonostratigraphic terrane, Wrangellia (Jones and others, 1977; Berg and others, 1978).

Although generally similar in recording a change from mafic volcanism to the deposition of calcareous sediments, the Karnian part of the section typical of Wrangellia in southern Alaska differs from the at least partly correlative rocks of the Chilkat Peninsula in some significant ways. The upper part of the Nikolai Greenstone is formed of subaerial basalt flows rather than submarine pillow lavas, and the lower part of the overlying Chitistone Limestone is formed of pure inner-platform carbonate rocks devoid of open-marine shelly fossils, in contrast to the impure calcareous rocks of the Chilkat Peninsula.

Despite these distinctions, the Chilkat Peninsula sequence, and hence the Taku terrane, conceivably could be a more offshore facies of the succession that characterizes Wrangellia. In some respects the Karnian rocks of the Chilkat Peninsula differ from those typical of Wrangellia in the same way as do those regarded as part of Wrangellia on Vancouver Island. If so, the Taku and far-traveled Wrangellia terranes would have shared the same displacement history, aside from subsequent offset of the Taku terrane by the Denali fault system. Determination of the paleomagnetic poles for the dated rocks of the Chilkat Peninsula, planned for the 1979 field season, should provide a crucial test of this possibility.

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Mineral resource evaluation method used in Glacier Bay National Monument Wilderness Study Area, southeastern Alaska

By Donald Grybeck and David A. Brew

The results of the joint U.S. Geological Survey-Bureau of Mines mineral resource investigation of Glacier Bay National Monument (Brew and others, 1978; Johnson, 1978) are summarized elsewhere in this volume (Brew and others, 1979). The method used to estimate the undiscovered hypothetical and speculative resources (Brew and others, 1979, fig. 51) differs significantly from that used in most wilderness reports (for example, Berg and others, 1977; Weis and others, 1976) and from that used in the Alaska Mineral Resource Assessment Program (AMRAP) (Grybeck and De Young, 1978, table 2; Berg and others, 1978). The most important difference is that the method used in Glacier Bay uses subjective judgments about the economic viability of different kinds of mineral deposits to provide decisionmakers with pertinent, understandable information on present and near-future mineral resource values. Consequently, the results may not remain current for as long as results from some other approaches.

The method integrates and synthesizes regional geology, geochemistry, geophysics, exploration and production history, accessibility, surficial cover, and, to some extent, economic factors involved in exploration, mine development, and mining. This synthesis leads to recognition of ore environments that define a favorable area and then requires definition of deposit-type, -size, and -grade models appropriate to those environments.

Two kinds of deposit models are used: 1) if a known deposit in the area is close to the minimum tonnage and grade considered likely to attract serious development interest, then it is used as the model for that area; 2) otherwise, a conceptual model meeting those minimum standards is used. The models are the most controversial part of the method because they involve subjective judgment about the size, tenor, and (or) value required for a deposit in a given area to be considered for immediate or near-future intensive exploration, development as a mine, and actual mining. The models focus on the current value of an exploitable resource, rather than on long-term value or total amount of metal present.

The grade and tonnage models of Grybeck and De Young (1978) are important guides in the selection of deposit models because they provide basic information on the size-frequency distribution of major mineral deposit types. The actual models chosen for the area studied are stated clearly, so that the informed reader can accept, reject, or modify the conclusions reached. In the Glacier Bay National Monument study we used the models in table 13; they are not all appropriate to other areas.

After deposit models have been chosen, the method requires four major decisions, each more subjective, as follows:

Define the favorable area: The boundaries of favorable areas are defined primarily by geology as it relates to a specific deposit type; they are also influenced by the size and significance of known deposits, geochemistry, geophysics, and history of previous exploration.

Estimate the maximum number of "permissible" deposits: The maximum number of deposits that are "geologically permissible" within the favorable area is estimated by applying the deposit model to the favorable area. The goal is an estimate of the maximum number of the defined model that could be expected to occur within the favorable area. As an example, an estimated maximum of five significant porphyry copper deposits, each underlying about 4 km^2, might occur within a 400-km^2 favorable area.

TABLE 13.—*Minimum tonnage and grade of hypothetical deposits judged likely to attract serious economic interest, Glacier Bay National Monument, Alaska*

Deposit type	Size (metric tons)	Grade (%)
Magmatic segregation nickel-copper	80,000,000	0.53 Ni, 0.33 Cu
Porphyry copper	45,000,000	0.4 Cu
Porphyry molybdenum	90,000,000	0.15-0.20 Mo
Volcanogenic (felsic and intermediate) sulfide	900,000	1.5 Cu, 2.0 Zn
Copper-tungsten-gold-silver skarn	Gross-in-place metal value of $2,000,000	

Estimate the likelihood of occurrence of "permissible" deposits: All available information, including the grade and tonnage models of Grybeck and De Young (1978), are considered in light of the knowledge, experience, and judgment of those making the estimate to arrive at the probability of occurrence of any or all of the "geologically permissible" deposits. Using the same example as above, the estimated probability that two of the deposits are present might be only 1 in 5, or 0.2.

Estimate the probability of discovery of the "permissible" deposits: In an area such as Glacier Bay National Monument, glaciers, snowfields, thick surficial deposits, extremely rugged terrain, and forests conceal much of the bedrock and limit the effectiveness of intensive surface prospecting methods. Thus some deposits may not be discoverable, even though they are present. Using the same example, the probability of discovering the two deposits might be estimated to be 1 in 2, or 0.5. Thus there would be a 1 in 10 chance of actually discovering the two deposits postulated in that favorable area. In practice, this and the above decision are commonly combined into a single estimate of how many model deposits actually occur and are discoverable.

The overall goal of this resource estimation process is to communicate to decisionmakers all the information in the minds of those who know most about the mineral resources of a given area. The process is admittedly imprecise and imperfect, but communication of the results does provide more usable and, we believe, better information than would otherwise be available.

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Summary of mineral resources, Glacier Bay National Monument Wilderness Study Area, southeastern Alaska

By David A. Brew, Donald Grybeck, and Bruce R. Johnson

During the 1975 through 1977 field seasons, the U.S. Geological Survey and Bureau of Mines cooperated on a mineral resource evaluation project in Glacier Bay National Monument. The main products of the evaluation are the estimates of identified resources by A. L. Kimball, J. C. Still, and J. L. Rataj of the Bureau of Mines (Brew and others, 1978) and the estimates of undiscovered resources by the present authors using the method described by Grybeck and Brew (1979).

The study identified six important mineral deposits with identified resources (1-6 on fig. 50) located in six areas (A, B, D-G on fig. 50) that also have undiscovered hypothetical resources. (The resource terms used here are shown on fig. 51.) Three additional areas (C, H, I on fig. 50) have undiscovered speculative resources. The elements of greatest economic interest are nickel, molybdenum, copper, zinc, and gold.

The Pacific beach sands favorable area (A) has produced placer gold and contains both inferred and hypothetical resources of ilmenite and gold. It is unlikely that these resources will be economically attractive in the near future, even though large tonnages are present.

The Crillon-La Perouse favorable area (B) includes the Brady Glacier magmatic nickel-copper deposit (1), which contains about 80 million metric tons of indicated resources with 0.53 percent nickel, 0.33 percent copper, and an unspecified amount of platinum group metals. In addition, the deposit contains 80 million metric tons of inferred resources of the same grade. The favorable area is estimated to have another 80 million metric tons of hypothetical resources of the same grade.

The Mount Fairweather favorable area (C), although very poorly known, has an ore environment like that of the Crillon-La Perouse area, and 82 million metric tons of speculative resources with 0.53 percent nickel and 0.33 percent copper is estimated to be present.

The Margerie Glacier favorable area (D) includes the Margerie Glacier porphyry-copper deposit (2) and the Orange Point volcanogenic sulfide deposit (3). The Margerie Glacier deposit contains 145 million metric tons of inferred resources with 0.2 percent copper, 0.27 g/t (grams per metric ton) gold, 4.5 g/t silver, and 0.01 percent tungsten. The Orange Point deposit contains 0.25 million metric tons of inferred resources with 2.7 percent copper, 5.2 percent zinc, 1 g/t gold, and 34 g/t silver, as well as 0.47 million metric tons of inferred resources containing 0.4 percent copper, 0.3 percent zinc, 0.2 g/t gold, and 12 g/t silver. In addition, the favorable area also is estimated to contain 0.9 million metric tons of hypothetical resources with 1.5 percent copper and 2.0 percent zinc, and further unquantified speculative copper and zinc resources.

The Reid Inlet favorable area (E) has produced gold from vein deposits (4) and is estimated to contain about 480 kg of hypothetical gold resources.

The Rendu Glacier favorable area (F) includes the "massive chalcopyrite" skarn deposit (5), which contains 0.004 million metric tons of inferred resources with 0.5 percent tungsten, 5.0 percent copper, 240 g/t silver, and 5.2 g/t gold. The favorable area also has unquantified speculative copper and tungsten resources.

The Muir Inlet favorable area (G) includes the Nunatak porphyry-molybdenum deposit (6), which contains 7.4 million metric tons of indicated resources with 0.06 percent molybdenum and 0.02 percent copper, 124 million metric tons of indicated resources with 0.04 percent molybdenum and 0.02 percent copper, and 8.3 million metric tons of inferred resources with 0.06 percent molybdenum and 0.02 percent copper. The area also is estimated to have 90 million metric tons of hypothetical resources with 0.15 to 0.20 percent molybdenum and unquantified speculative resources of copper and molybdenum.

The Casement Glacier favorable area (H) also

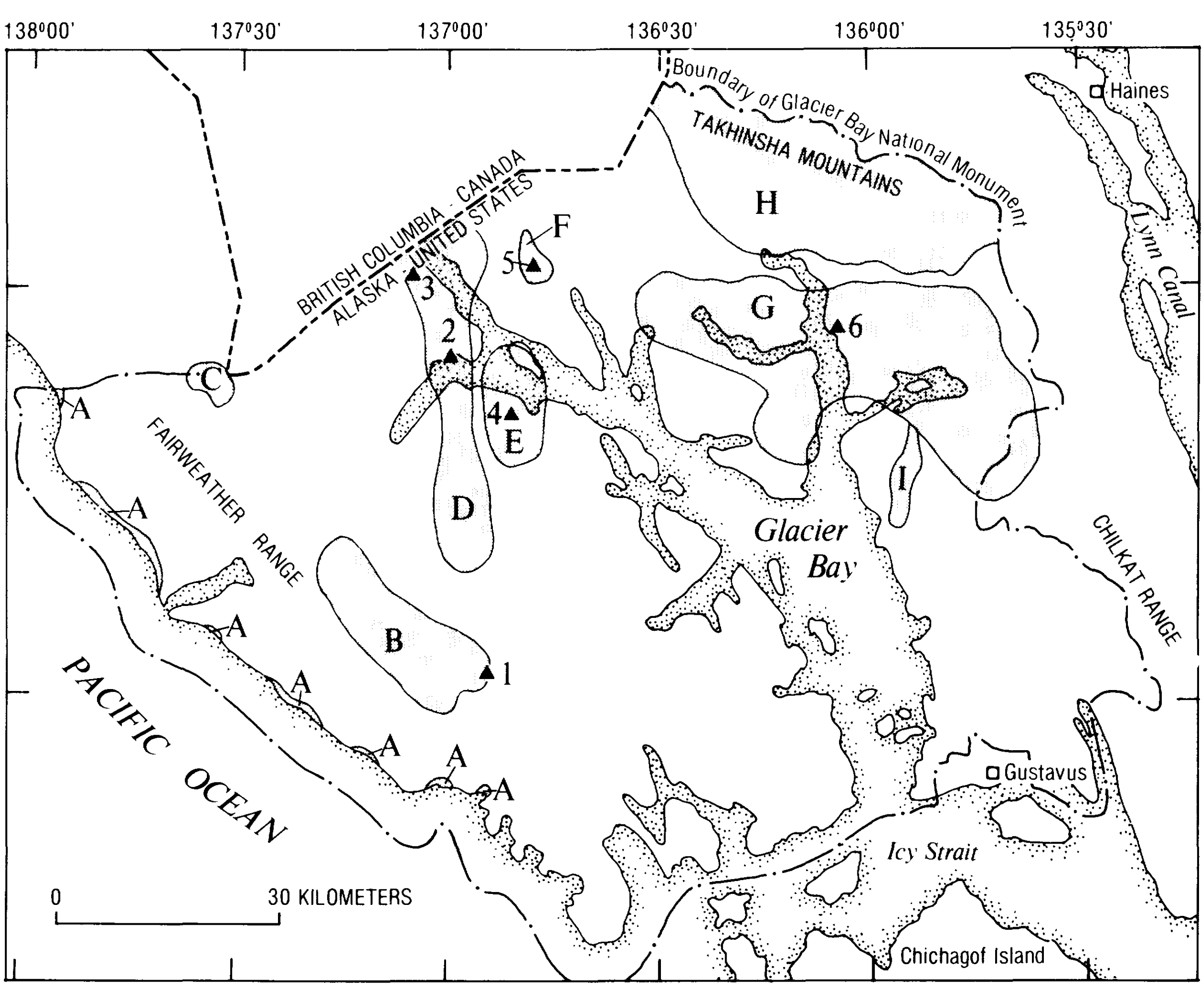

FIGURE 50.—Map of Glacier Bay National Monument, Alaska, showing known significant deposits (triangles) and favorable areas (patterned). Letters refer to description of resource areas in text.

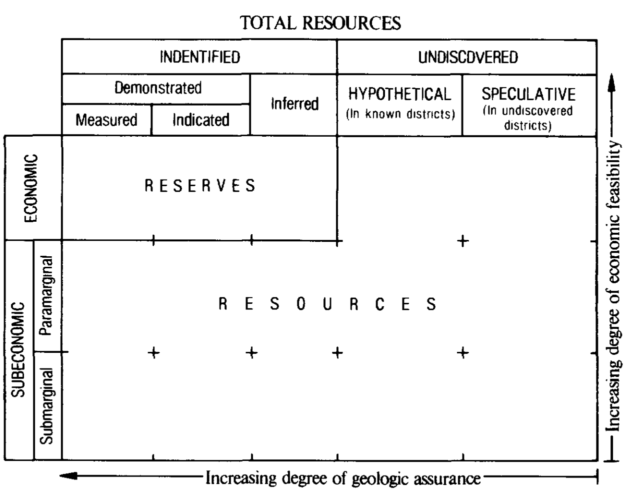

FIGURE 51.—Classification of mineral resources used by U.S. Bureau of Mines and U.S. Geological Survey (1976).

contains unquantified speculative molybdenum and copper resources. Part of the area also has unquantified speculative copper-zinc resources in a volcanogenic environment.

The White Glacier favorable area (I) also contains unquantified speculative zinc and copper resources in a volcanogenic environment.

These deposits and favorable areas are in the parts of the monument that are best known geologically and geochemically. The presence of significant metallic mineral resources in other areas cannot be ruled out. Glacier Bay National Monument is more highly mineralized than most similar-size areas in southeastern Alaska, and it is likely that it contains more deposits and favorable areas of the types described here. Other types of deposits may occur as well. Coal, oil and gas, nuclear fuels, geothermal energy, and industrial minerals are unlikely to be present in amounts of economic significance, although they are either known to occur or could logically occur in the monument.

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Neoglacial sedimentation in Glacier Bay, Alaska

By Paul R. Carlson, Mark C. Wheeler, Bruce F. Molnia, and Thomas J. Atwood

High-resolution seismic profiles obtained in Glacier Bay during a cruise of the R/V *Growler* in September 1978 provide new information on sediment thicknesses and rates of sediment accumulation in areas that have been deglaciated within the past 200 years (fig. 52). These seismic profiles show at least two stratigraphic units above the crystalline and metasedimentary bedrock mapped by Brew and others (1978). The lower stratigraphic unit includes what appears to be ice-contact, glacial-fluvial, and glacial-marine deposits. This lower unit is characterized seismically by irregular, discontinuous, and often hummocky reflectors, typical of a till, and by occasional sediment masses with parallel reflectors that we interpret as stratified drift. The upper stratigraphic unit is characterized seismically by even, continuous, parallel reflectors that are the result of deposition of glacial flour carried into the fiords by glacial melt water. Some of the layers in this upper unit may have been deposited by density flows that developed from slumps, especially near active ice fronts.

The glaciers that occupied West Arm, including Johns Hopkins and Tarr Inlets, have retreated a total of 105 km from the mouth of Glacier Bay since 1780. The high-resolution seismic profiles show sediment accumulations of variable thicknesses in these fiords. In the upper halves of both Tarr and Johns Hopkins Inlets, post-1912 sediments more than 160 m thick have collected in depressions on the fiord floor; these thicknesses indicate rates of accumulation as high as 2.3 m/yr for Johns Hopkins Inlet and 1.7 m/yr for Tarr Inlet. The thickest deposit of postglacial sediment in Glacier Bay, found in lower West Arm, is at least 200 m thick and has been accumulating since 1860. Thus the average rate of accumulation for this deposit is 1.7 m/yr (fig. 52). Slower rates were documented in other fiords; sediment in Geikie Inlet, for example, accumulated at a rate of about 0.5 m/yr.

Muir Inlet, which has lengthened 45 km in the last 120 years by the retreat of Muir Glacier and tributaries, has accumulations of postglacial sediment as thick as 120 m in the central and deepest part of its channel. In the part of upper Muir Inlet where the terminus of Muir Glacier was located between 1961 and 1964, the bedrock basin contains a maximum of 60 m of sediment (fig. 52). This thickness indicates an average rate of accumulation of between 3.5 and 4.3 m/yr. However, not all relatively stationary ice-front positions correlate with thick sedimentary bodies. For example, very little neoglacial sediment ($\sim$15 m) exists adjacent to Riggs Glacier, a tributary of Muir Glacier, whose ice front has changed little since 1960. Wachusett Inlet, a 23-km-long fiord formed by the post-1925 retreat of Plateau Glacier, has only small pockets of sediment in its upper end (5-10 m thickness), and the sediment accumulating in its lower end (as much as 65 m thickness; rate 1.3 m/yr) may be entering as suspended sediment from Muir Inlet. Adams Inlet, a 14-km-long fiord, has almost no sediment in its lower end, but a thick ($\sim$60 m) post-1950 accumulation in its upper end. The maximum average accumulation rate of the sediment in upper Adams Inlet is nearly 2 m/yr.

In the main channel of lower Glacier Bay northwest of Bartlett Cove, where tidal currents at times exceed 6 knots (U.S. Department of Commerce, 1969, p. 210), little or no postglacial sediment has accumulated. Our initial interpretations of the high-resolution records suggest the presence of several tens of meters of

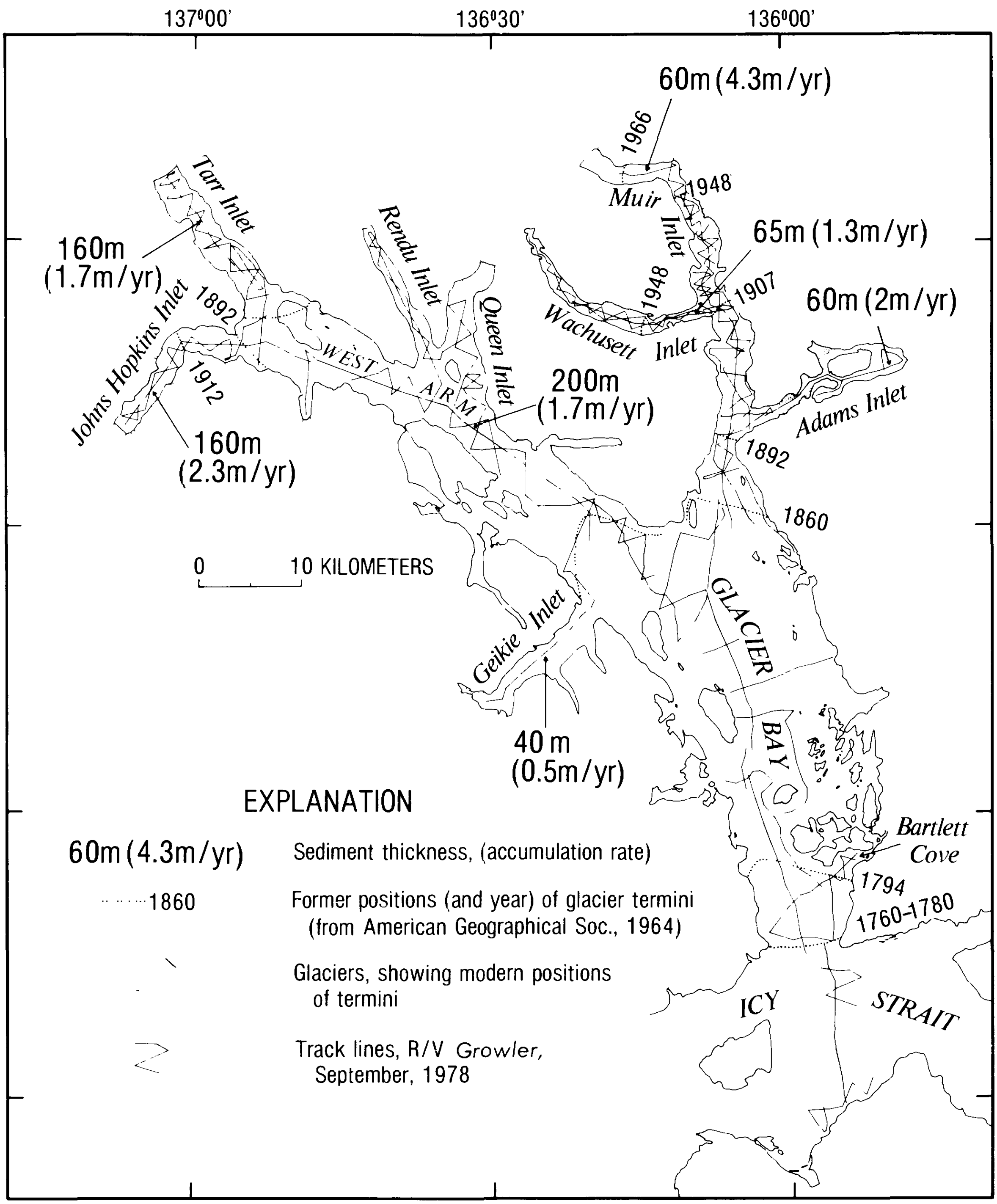

FIGURE 52.—Sketch map of Glacier Bay showing seismic reflection lines, sediment thickness, sediment accumulation rates, and former positions of glacier termini.

neoglacial sediment east of the main lower-bay channel. Here, however, the seismic stratigraphy is less clearly defined than in West Arm and Muir Inlets. A sediment sampling program is planned for the 1979 field season to enhance our seismic interpretations.

Within the constraints of our present knowledge, no absolute correlations can be made between time since ice retreat, rate of retreat, or thickness of accumulated sediment. However, in many areas of Glacier Bay, rates of accumulation and thicknesses of recent sediment are high and exceed those reported for most other types of marine deposition.

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Significance of geotectonics in the metallogenesis and resource appraisal of southeastern Alaska: A progress report

By H. C. Berg

Southeastern Alaska (fig. 53) consists of parts or all of nine fault-bounded geotectonic (tectonostratigraphic) terranes (Berg and others, 1978). Each terrane is characterized by distinctive stratigraphic sequences that differ substantially from those of adjoining terranes. Their grossly dissimilar geologic and structural histories imply juxtaposition by large-scale tectonic transport. This juxtaposition produced a mosaic of discrete tectonic elements that record a long and complex history of amalgamation and accretion to the continental margin of North America. The history of amalgamation began in Permian time, the age of the oldest rocks known to overlap any two of the terranes. The major episode of accretion apparently was in Late Cretaceous time, the age of the youngest regionally penetratively deformed rocks in southeastern Alaska. Subsequent tectonic activity has been mainly (a) redistribution of the terranes along major fault zones, such as the Chatham Strait fault, and (b) Cenozoic intrusion, thermal metamorphism, and local deposition of continental volcanic and sedimentary rocks.

The differences among the terranes imply fundamental differences in their origin and tectonic history, and consequently in the origin, distribution, types, controls, and history of mineral deposits that occur in them. A key factor in testing and applying such a geotectonic model in metallogenic analysis and resource appraisal is that it predicts basic differences in mineral deposits that originated in different terranes before they were assembled. It also predicts (a) potentially important modifications to preexisting mineral deposits during and after amalgamation and accretion of the terranes, and (b) important regional similarities among certain types of mineral deposits that originated during and after final accretion of the terranes.

Table 14 illustrates possible applications of this geotectonic model to selected mineral deposits in southeastern Alaska. The classifications and interpretations presented are preliminary or speculative and are based on my own reconnaissance investigations, on my interpretations of reports published by U.S. Geological Survey colleagues, and on information released by mining companies. Such classifications and interpretations may change substantially after detailed future studies of the region's mineral deposits, geology, and tectonics.

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Intrusive rock belts of southeastern Alaska

By David A. Brew and Robert P. Morrell

Although reconnaissance geologic mapping is incomplete in southeastern Alaska, the available information is sufficient to reach preliminary conclusions about the distribution, composition, and age of the intrusive rocks in the region (Brew and Morrell, 1979). These conclusions, in turn, are the basis for the definition of intrusive rock belts presented here.

About 30 percent of the 175,000 km^2 of southeastern Alaska is underlain by intrusive igneous rocks. Almost all of these rocks are grouped in six major north-northwest-striking belts or provinces (fig. 54) between the continental margin and the international boundary with Canada. From west to east, they are: the Fairweather-Baranof belt of early to middle

FIGURE 53.—Map of southeastern Alaska showing ► geotectonic terranes and locations of mineral deposits.

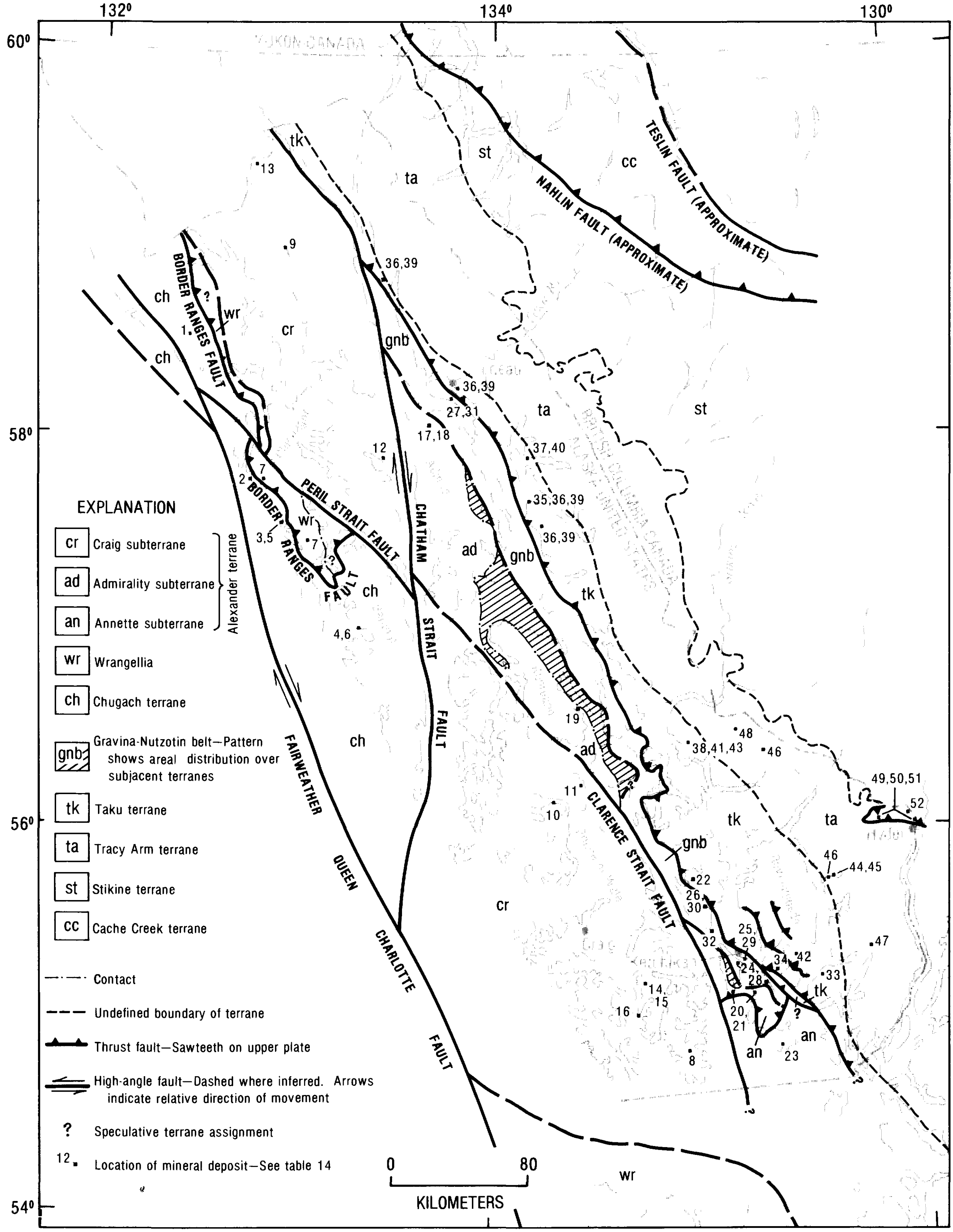
132°
134°
130°
60°
58°
56°
54°
TESLIN FAULT (APPROXIMATE)
NAHLIN FAULT (APPROXIMATE)
BORDER RANGES FAULT
PERIL STRAIT FAULT
CHATHAM STRAIT FAULT
CLARENCE STRAIT FAULT
FAIRWEATHER QUEEN CHARLOTTE FAULT
cr
ad
an
wr
ch
gnb
tk
ta
st
cc
EXPLANATION
cr Craig subterrane
ad Admirality subterrane
an Annette subterrane
Alexander terrane
wr Wrangellia
ch Chugach terrane
gnb Gravina-Nutzotin belt—Pattern shows areal distribution over subjacent terranes
tk Taku terrane
ta Tracy Arm terrane
st Stikine terrane
cc Cache Creek terrane
Contact
Undefined boundary of terrane
Thrust fault—Sawteeth on upper plate
High-angle fault—Dashed where inferred. Arrows indicate relative direction of movement
? Speculative terrane assignment
12 Location of mineral deposit—See table 14
0
80
KILOMETERS

TABLE 14.—*Tentative classification of selected mineral deposits in southeastern Alaska based on proposed geotectonic model*

[Abbreviations and symbols used: Cu, Pb, Zn, etc. = copper, lead, zinc, etc.; Ba = barite; REE = rare earth elements. A vertical arrow indicates that the deposit (type) may overlap geotectonic terranes; a horizontal arrow indicates that the deposit (type) may overlap tectonic events. Numbers in parentheses correspond with locations of mineral deposits shown in figure . Mineral deposits (types) interpreted to have formed by redistribution or reconcentration of preexisting deposits are preceded by the same lower-case letters in columns I-III; mineral deposits (types) not preceded by lower-case letters are interpreted to be genetically distinct from those in columns I or II]

Geotectonic terrane	I. Examples of pre-amalgamation types of mineral deposits or mineral deposit types unique to terrane	II. Examples of mineral deposits formed by redistribution or reconcentration during amalgamation or accretion of terrane	III. Examples of mineral deposits or types originating during or after final accretion of terrane
Chugach	a. Brady Glacier(1), W. Chichagof Island (2): Stratiform Ni-Cu deposits in Mesozoic or Cenozoic layered gabbro and ultramafic rocks.		
	b. Chichagof(3), Baranof(4) Islands: Stratabound sulfide deposits in upper Mesozoic sedimentary and volcanic rocks.	b. Chichagof(5)-Sitka(6) district: auriferous quartz veins.	
Wrangellia	a. Stratabound Cu(-Au-Pb-Zn-Ag) deposits in Triassic(?) mafic metavolcanic rocks(7).		
Alexander			
Craig	a. Bokan Mountain(8): Magmatic U-Th deposits in early Mesozoic peralkaline granite.		Nunatak(9), Shakan(10): Porphyry Mo deposits in Cenozoic plutons.
	b. Salmon Bay(11): REE, U-Th in Paleozoic(?) carbonatite(?).		
	c. N.E. Chichagof Island(12): Stratiform(?) gypsum deposits in Carboniferous limestone and clastic sequence.		
	d. Glacier Creek(13): Stratabound volcanogenic(?) Ba(-Zn-Pb-Cu) deposits in Paleozoic(?) mafic volcanic and clastic sequence.		
	e. Copper Mountain district(14): Stratabound volcanogenic Cu-Zn-Ag-Au deposits in Precambrian(?) Wales Group mafic metavolcanic rocks.	e. Copper Mountain district (15): Cu-Zn-Ag-Au skarn deposits in Wales Group carbonate intruded by mid-Cretaceous plutons.	
	f. Lime Point(16): Stratiform barite deposits in Precambrian(?) Wales Group marble.		
Admiralty	a. Greens Creek ("Big Sore")(17): Stratabound massive Pb-Zn-Ag(-Ba) deposit in Paleozoic or Triassic metavolcanic rocks.	a. Northern Admiralty Island(18): Auriferous quartz-carbonate veins.	
	b. Castle Island(19): Stratiform(?) barite deposit in Triassic(?) metavolcanic(?) rocks.		
Annette	a. Annette-Gravina Island(20): Stratabound Cu-Pb-Zn-Ag-Ba(-Au) deposits in Triassic(?) felsic metavolcanic rocks.	a. Annette-Gravina Island(21): Cu-Ba, etc. breccia lodes in thrust zones.	
Gravina-Nutzotin belt	a. Union Bay(22), Duke Island(23): Stratiform Fe-Ti deposits in late Mesozoic zoned ultramafic plutons.		
	b. Annette-Gravina Island(24), Ketchikan (25), Helm Bay(26), Treadwell(27): Stratabound "disseminated gold" and basemetal sulfide deposits in late Mesozoic intermediate to mafic metavolcanic rocks.	b. Annette-Gravina Island(28), Ketchikan(29), Helm Bay(30), Treadwell (31): Auriferous quartz(-carbonate) veins.	b. Camaano Point(32): Sb veins.
Taku	a. Roe Point(33), Moth Bay(34), Point Astley(35), Juneau gold belt(36), Sweetheart Lake area(37), Groundhog Basin(38): Stratabound Cu-Pb-Zn(-Au-Ag) deposits in late Paleozoic or Mesozoic volcanic, volcaniclastic rocks.	a. Juneau gold belt(39), Sweetheart Lake area(40), Groundhog Basin(41), Sealevel(42): Auriferous polymetallic quartz(-carbonate) veins.	Groundhog Basin(?)(43): Porphyry Mo deposits in Cenozoic plutons.
Tracy Arm	a. Walker Cove(44): Stratabound massive Cu-Au(-Ag-Zn) deposits in schist, gneiss, and amphibolite of unknown premetamorphic age.	a. Walker Cove(45): Auriferous polymetallic quartz veins. Walker Cove, N. Bradfield Canal(46): Fe-Cu-Pb-Zn-Ag skarn deposits. →	Quartz Hill(47), Cone Mountain (48): Porphyry Mo, U-Th deposits in Cenozoic plutons.
Stikine	a. Hyder-Texas Creek area(49): Porphyry(?) and stratabound Cu-Pb-Zn-Ag-Au deposits in early Mesozoic volcanoplutonic complex ("Hazelton-Texas Creek").	a. Hyder-Texas Creek(50): Mo, W, polymetallic quartz veins. Polymetallic skarn deposits(51). →	Porphyry Cu, Mo(?) deposits in Cenozoic plutons(52).

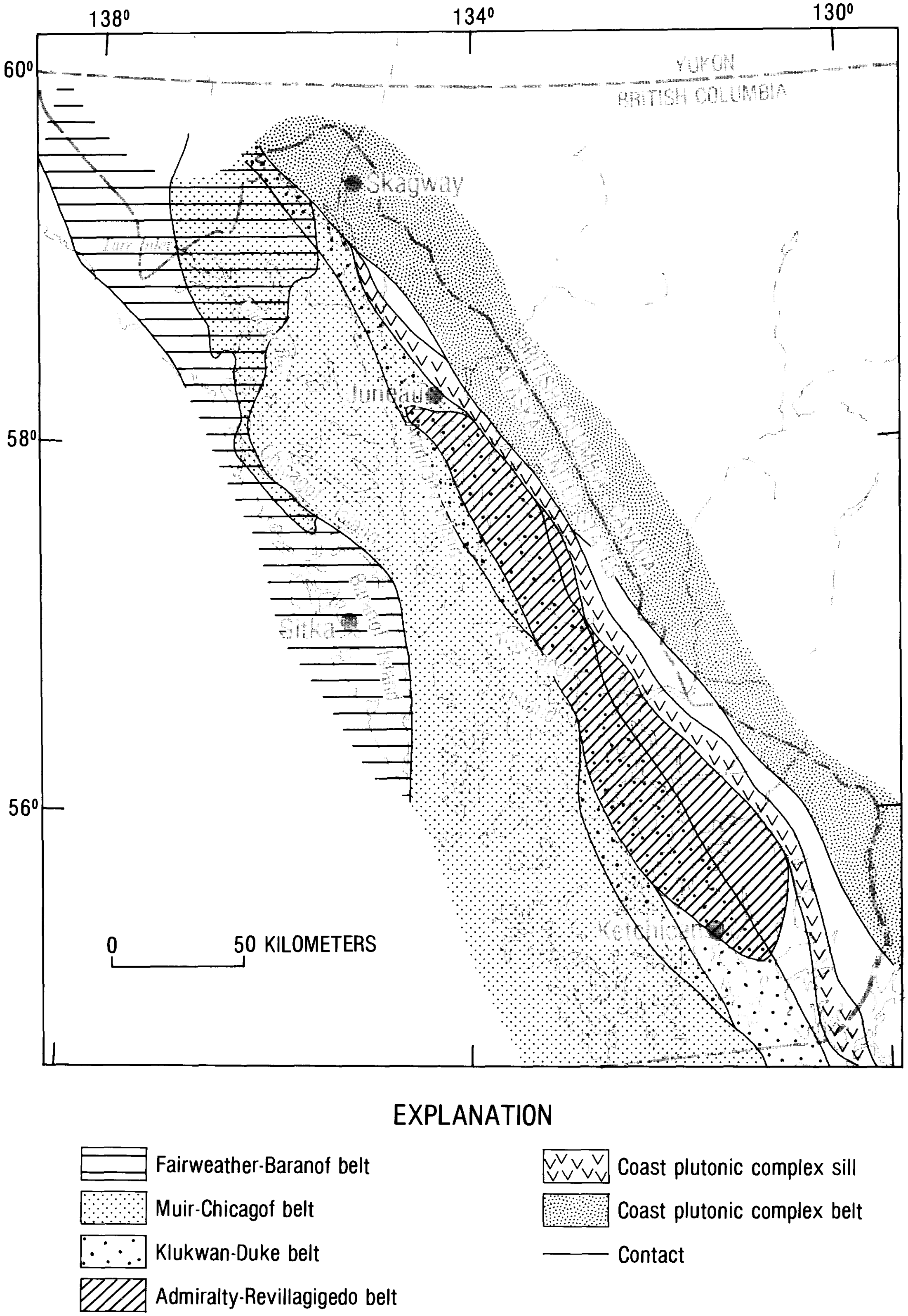

FIGURE 54.—Generalized map showing major intrusive rock belts of southeastern Alaska.

Tertiary granodiorite; the Muir-Chichagof belt of middle Cretaceous tonalite and granodiorite; the Admiralty-Revillagigedo porphyritic granodiorite, quartz diorite, and diorite belt of unknown, but perhaps Jurassic or Cretaceous, age; the Klukwan-Duke belt of concentrically zoned or Alaska-type ultramafic-mafic plutons of middle Cretaceous age which is mainly within the Admiralty-Revillagigedo belt; the Coast plutonic complex tonalite sill of unknown, but perhaps middle Cretaceous, age; and the Coast plutonic complex belt of early to middle Tertiary granodiorite and quartz monzonite.

Not shown on figure 54 are five minor belts: layered gabbro complexes of inferred middle Tertiary age within and probably part of the Fairweather-Baranof belt; the Chilkat-Chichagof belt of Jurassic granodiorite and tonalite within the Muir-Chichagof belt; the Sitkoh Bay alkaline complex, Kendrick Bay pyroxenite to quartz monzonite, and Annette and Cape Fox trondhjemite complexes, all of Ordovician(?) age, within the Muir-Chichagof belt; the Kuiu-Etolin volcanic-plutonic belt of middle Tertiary age extending from the Muir-Chichagof belt eastward into the Admiralty-Revillagigedo belt (Brew and others, 1979); and the Behm Canal belt of middle to late Tertiary granites within the Coast plutonic complex belt. In addition, a few mafic-ultramafic bodies occur within the Fairweather-Baranof, Muir-Chichagof, and Coast plutonic complex belts.

Palinspastic reconstruction of 200 km right-lateral movement on the Chatham Strait fault (Ovenshine and Brew, 1972) does not significantly change the pattern of the major belts but does bring the Ordovician(?) complexes closer together. Reconstruction of the minor offsets known to affect Tertiary(?) dike swarms (Brew and others, 1976), middle Tertiary plutons of the Fairweather-Baranof belt (Loney and others, 1967), and middle Cretaceous plutons of the Muir-Chichagof belt (Loney and others, 1975) likewise does not significantly change the pattern.

The major belts are within the tectonostratigraphic terranes defined by Berg and others (1978) (see also Berg, 1979) as follows: the Fairweather-Baranof belt largely in the Chugach and Alexander terranes; the Muir-Chichagof belt in the Alexander and Wrangell (Wrangellia) terranes; the Admiralty-Revillagigedo belt in the Gravina-Nutzotin and Taku terranes; the Klukwan-Duke belt in the Gravina-Nutzotin, Taku, and Alexander terranes; and the Coast plutonic complex belt in the Tracy Arm and Stikine terranes.

Some of the belts are spatially and, in a few cases, genetically related to significant metallic mineral deposits. The Fairweather-Baranof belt granodiorites may be the locus of gold, copper, and molybdenum occurrences. The layered gabbros within that belt have magmatic copper-nickel deposits. The Coast plutonic complex sill is spatially associated with the Juneau gold belt with its gold, silver, copper, lead, and zinc occurrences; the Klukwan-Duke ultramafic-mafic belt contains iron deposits; and the Behm Canal belt has porphyry molybdenum deposits.

Tectonic interpretation of the belts is uncertain, but a few preliminary suggestions are possible: The Muir-Chichagof belt and the Admiralty-Revillagigedo belt are currently interpreted as magmatic arcs formed during subduction events. In general, the other intrusive belts are spatially related to structural discontinuities, but genetic relations, if any, are not yet interpretable. The Coast plutonic complex tonalite sill was probably emplaced along a post-Triassic, pre-middle Cretaceous suture (Brew and Ford, 1978) that almost corresponds to the Tracy Arm-Taku terrane contact (Berg, 1979). The boundary between the Admiralty-Revillagigedo and Muir-Chichagof belts nearly coincides with the Seymour Canal-Clarence Strait lineament; that lineament is also probably a major post-Triassic suture. The relation between known structural discontinuities and the two early to middle Tertiary belts, the Fairweather belt and the Coast plutonic complex belt, is not clear, although the Fairweather belt is approximately parallel to the Tarr Inlet suture zone.

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The Wrangell terrane ("Wrangellia") in southeastern Alaska: the Tarr Inlet suture zone with its northern and southern extensions

By David A. Brew and Robert P. Morrell

The Tarr Inlet suture zone in Glacier Bay National Monument, Alaska, consists of a narrow strip of structurally complicated, diverse, low-grade metamorphic rocks separating the homogeneous, low-grade metamorphic rocks of the Fairweather block to the west (Brew and others, 1978; Brew and Morrell, 1978, 1979) from the predominantly intrusive rocks in the Alexander terrane to the east (fig. 55). The phyllite, slate, conglomerate, chert, greenstone, greenschist, and marble of the suture zone were interpreted to be Permian(?) on the basis of lithologic correlation with fossiliferous Permian rocks 60 km away in the northeastern part of the monument, and the zone was thought to be the result of a post-Permian, pre-middle-Cretaceous collision between the Fairweather block and a large block of lower and middle Paleozoic rocks of the Alexander terrane to the east. The age of the Fairweather block was interpreted to be probably Precambrian or early Paleozoic (Brew and others, 1977); this block is now interpreted to be Cretaceous (Brew and Morrell, 1978). Reexamination in this paper of both old and new information suggests that the suture zone rocks are equivalent to the Wrangell terrane ("Wrangellia") of Berg, Jones, and Coney (1978), but both the distribution and significance of the suture zone are broader than previously suspected.

The four criteria (1. eastern limit of homogeneous turbidites; 2. structural complexity; 3. western limit of foliated Cretaceous granitic rocks; and 4. western limit of thick Paleozoic

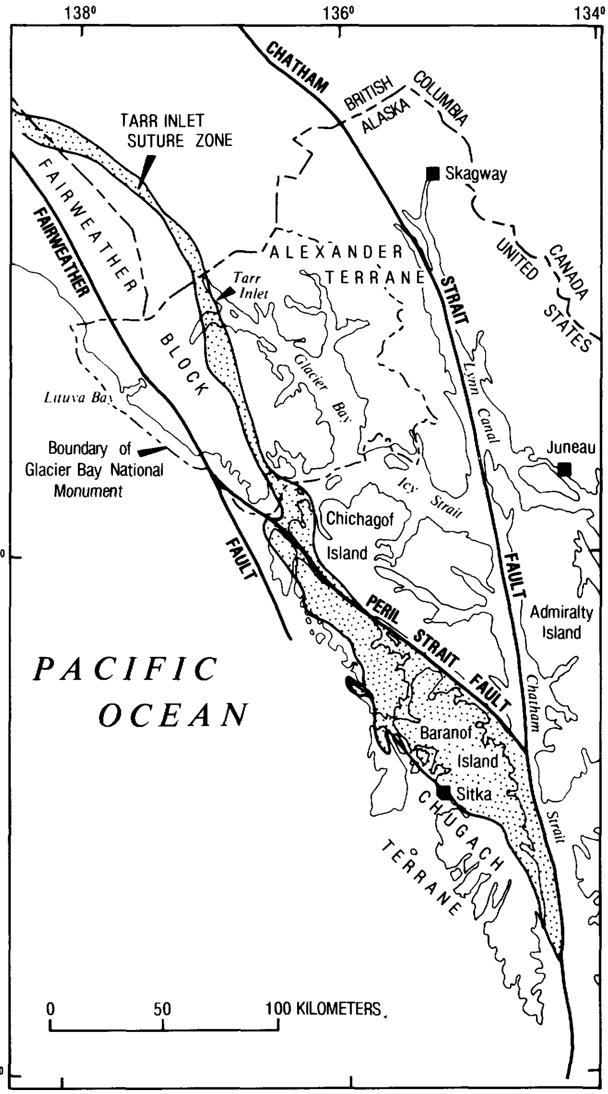

FIGURE 55.—Wrangell terrane (patterned) between lat 59°30'N. and lat 57°15'N.

carbonate rocks) that define the suture zone in Glacier Bay have been used by Campbell and Dodds (1979) to extend the suture zone northwestward for about 100 km through British Columbia to the international boundary east of Yakutat (fig. 55). They interpret the zone there to be bounded on the west by the Border Ranges fault and on the east by the Art Lewis fault. The rocks in the suture zone are described as highly deformed metavolcanic greenschist, argillite, some metachert and conglomerate, and minor light-gray limestone. They are cut by Jurassic and (or) Cretaceous plutons and are inferred to be Permian and (or) Triassic in age. Still farther north, equivalent rocks have been mapped as a separate unit in Yukon Territory north of Mount Logan (Campbell and Dodds, 1978). Those exposures are about 50 km east of and continuous with rocks clearly equivalent to the type "Wrangellia" of Jones and others (1977).

Application of the same criteria to the rocks on Baranof and Chichagof Islands to the south (Loney and others, 1975) defines the area shown on figure 55. Omitting details, the western boundary of the zone is the eastern limit of the Sitka Graywacke; areas of great structural complexity are generally confined to the western part of the zone; foliated Jurassic and (or) Cretaceous granitic rocks invade most of the zone north of Baranof Island; and thick Paleozoic carbonates and related clastic rocks define the eastern boundary of the zone. Neither zone boundary is well exposed, but no fault or unconformity has been recognized at the western limit, and the eastern limit is almost wholly obscured by younger faults and granitic plutons.

The width of the belt is relatively constant southward from the international boundary east of Yakutat to southern Chichagof Island where a noticeable widening is associated with abundant granitic bodies and a large fold on northern Baranof Island. The zone is truncated to the southeast by the Chatham Strait fault. Thus the whole zone as redefined here is a long (greater than 435 km), generally narrow (7 to 40 km) seam between relatively homogeneous turbidites of Cretaceous age to the west and lower to middle Paleozoic clastic, carbonate, and minor volcanic rocks to the east.

As noted previously, Brew and Morrell (1978) suggested that the suture zone rocks in Glacier Bay were Permian(?), and Campbell and Dodds (1979) suggest a Permian and (or) Triassic age for the rocks in the northern extension. Loney and others (1975) suggested a Triassic or Jurassic age for most of the rocks on Chichagof and Baranof Islands, which are here interpreted as within the zone; Plafker and others (1976) noted the occurrence of Early Cretaceous fossils in melange considered here to be within the zone. The zone rocks may thus be interpreted to be Permian and (or) Triassic, but they may in part have been incorporated in a younger melange.

The timing of the juxtaposition of the rocks of the suture zone with those to the east and west is uncertain, but we suggest that two events occurred. The invasion of the rocks of the suture zone by the Jurassic and Cretaceous granitic rocks that also occur in the Alexander terrane to the east indicates that the zone rocks had been deformed and joined to the Alexander terrane perhaps by Jurassic and at least by middle Cretaceous time. This dates the eastern contact as post-Permian and (or) Triassic and pre-Jurassic and Cretaceous. The plutons do not intrude either the Sitka Graywacke unit or the rocks of the Fairweather block, both of which are now interpreted by Brew and Morrell (1979) as probably Lower through Upper Cretaceous. The plutons also are interpreted to predate the possible melange within the suture zone. Middle Tertiary granitic rocks occur in the suture zone and bordering terranes (Brew and others, 1978). All the above information suggests that: 1) the turbidites were being deposited when the Alexander terrane and juxtaposed suture zone rocks were being intruded by the Cretaceous granitic rocks; 2) the Fairweather block rocks were distant from the suture zone rocks during Cretaceous time, and whatever separated the two terranes is now missing; and 3) the western contact of the suture zone is a post-Late Cretaceous, pre-middle Tertiary feature and is younger than the eastern contact. The Tarr Inlet suture zone rocks, therefore, are not a welt squeezed between two crustal blocks in a simple collision; rather they represent the remnants of a distinct terrane.

Berg, Jones and Coney (1978) interpret the Tarr Inlet suture zone in Glacier Bay to be Wrangell terrane ("Wrangellia"). The parts of Chichagof and Baranof Islands that we interpret to the part of the same zone, they assign in part to Wrangell terrane, but mostly to Chugach terrane. The interpretation given here revises the distribution of the Wrangell terrane on Chichagof and Baranof Islands and documents the probable connection of these rocks with the type "Wrangellia" (Jones and others, 1977).

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Correlation of the Sitka Graywacke, unnamed rocks in the Fairweather Range, and Valdez Group, southeastern and south-central Alaska

By David A. Brew and Robert P. Morrell

A very large belt of lithologically similar rocks of predominantly Cretaceous age extends around the Gulf of Alaska from the Shumagin Islands to Baranof Island. It includes the Shumagin Formation, Kodiak Formation, Valdez Group, unnamed rocks in Glacier Bay National Monument, and the Sitka Graywacke. These rocks are part of the subduction complex described in general terms by Plafker, Jones, and Pessagno (1977). This report describes in more detail the apparently thick turbidites and related rocks that occur in a continuous belt from north of Yakutat Bay southeastward through the Fairweather Range and Chichagof and Baranof Islands and significantly revises previous recent interpretations of the rocks in the Fairweather Range.

General lithologic and other information on the Sitka Graywacke is summarized in table 15. Decker, Nilsen, and Karl (1979) studied the Sitka Graywacke on western Chichagof Island and concluded that: (1) the unit is a sedimentary melange or broken formation, (2) middle-fan, inner-fan, and slope-type turbidite facies are present, (3) the fossiliferous strata that date the formation are shallow marine and occur in a probable submarine landslide block, and (4) more than one fan complex may be present.

Lithologic descriptions of the unnamed nonintrusive rocks that underlie the Fairweather Range (table 15) are from three widely separated localities where the amount of deformation and metamorphism are the least. The rocks in these exposures were deposited as turbidites and are accompanied by an extensive metabasalt unit. The thin- to medium-bedded graywacke interbedded with very thin- to thin-bedded shale and shale with minor graywacke probably represent an outer-fan-type environment. The rocks contrast with the Sitka Graywacke on western Chichagof Island in that no massive-appearing, very thick bedded graywacke is present and the proportion of fine-grained sediments is greater.

Plafker, Jones, and Pessagno (1977) did not recognize the continuity of this turbidite belt

TABLE 15.—*Lithologic and other information on the Sitka Graywacke, unnamed rocks in the Fairweather Range, and the Valdez Group*

Unit/Location	Dominant lithology Rock type(s)	Dominant lithology Features	Minor lithologies Rock type(s)	Minor lithologies Features	Age General	Age Basis	Metamorphism	Deformation	Remarks	References
Sitka Graywacke/ Baranof and Chichagof Islands	Graywacke	Very thick bedded; massive appearing; fine to coarse grained; light to medium gray; few argillite partings; no sedimentary structures	Argillite	Dark gray; some very thin bedded graywacke	Jurassic and Cretaceous	Berriasian pelecypods; Tithonian (?) pelecypod	Generally prehnite-pumpellyite-metagraywacke facies	Highly folded	Greenstone and greenschist common locally only on western Chichagof and eastern Baranof Islands.	Berg and Hinckley, 1963; Loney and others, 1975
			Breccia							
			Greenstone and greenschist							
			Limestone							
			Chert							
	Graywacke/ argillite	Turbidites; very thin to medium-bedded; abundant sedimentary structures	Conglomerate	Pebbles and cobbles of silicic volcanic rock, silicic plutonic rock, chert, quartzite						
Unnamed unit/ Fairweather Range: 1)Cape Spencer	Graywacke	Fine grained; medium to dark gray; 1-10 cm thick beds	Phyllite	Slaty; very fine grained; medium to dark gray; 1-10 cm thick layers	Cretaceous	No direct evidence	Slight, probably prehnite-pumpellyite metagraywacke facies	Foliated and cleaved	All graywacke and phyllite exposures are part of the "metagraywacke, phyllite, and muscovite schist" unit of Brew and others (1978). The closely associated "hornblende schist and gneiss" unit retains no original textures or structures but is of basaltic composition. It also extends northward past Yakutat.	Rossman, 1963; Brew and others, 1977; Brew and others, 1978; Brew and Morrell, 1978
2)Headwall of Desolation Glacier	Graywacke (60%)	Fine grained; 30 cm thick beds; conspicuous layers; light brown; no sedimentary structures observed	Phyllite (35%)	Dark gray; 5-cm thick layers	do	do	do	Open folds; lineated phyllite		
			Greenschist (5%)	Light green, flaky weathering						
3)South of Margerie Glacier	Phyllite	Fine grained; dark grayish brown	Graywacke semi-schist		do	do	do			
			Conglomerate (very minor)	Interlayered with graywacke; pebbles and cobbles of graywacke, chert, argillite, granitic rock in matrix of argillite or phyllite				Stretched pebbles		
Valdez Group/ north and northwest of Yakutat	Graywacke	Local sedimentary structures reported; dark gray to greenish gray	Mudstone		Late Cretaceous	Maestrichtian and Campanian (?) *Inoceramus*; Berriasian pelecypods	Variable, but mostly greenschist facies	Intense folding	Metavolcanic rocks are equivalent to "Hornblende schist and gneiss" unit noted above.	Sharp and Rigsby, 1956; Brabb and Miller, 1962; MacKevett, 1973; Campbell and Dodds, 1978; Tysdal and Plafker, 1978
			Conglomerate	Pebbles of argillite, chert, limestone, quartzite, granitic rock						
	Siltstone		Tuff							
	Argillite	Grayish black; poorly stratified	Pillow basalt		and Early Cretaceous					
			Volcanic breccia							
			Quartzite	Very fine to coarse grained						
			Limestone							

with the Sitka Graywacke. They considered the rocks to be part of their "upper Paleozoic metamorphic rocks and overlying Mesozoic shelf deposits" and thus did not include them in their subduction complex. Brew and others (1977) also ignored the continuity and suggested that several lines of evidence indicated a probable Precambrian or early Paleozoic age for the rocks. Both hypotheses are rejected here in favor of a Cretaceous age based on continuity with rocks of that age to the north and south. This interpretation is the same as Rossman's (1963) suggestion.

Although information on the Valdez Group (table 15) north of Yakutat lacks detailed lithologic descriptions, it is clear that the rocks are a turbidite sequence with significant amounts of volcanic rock. The lack of details notwithstanding, the Sitka Graywacke, the unnamed rocks of the Fairweather Range, and the Valdez Group show enough lithologic similarity and continuity to justify grouping them together. The available age information suggests that this supergroup may span all of the Cretaceous. The position of the turbidite belt on the northeast side of Plafker, Jones, and Pessagno's (1977) Cretaceous melange located along the west side of the Fairweather Range requires extremely large scale structural displacements of part of their accretionary flysch and melange terrane.

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Turbidite facies of the Sitka Graywacke, southeastern Alaska

By John Decker, Tor H. Nilsen, and Susan Karl

The Sitka Graywacke, of Late Jurassic and Early Cretaceous age, is a thick, highly deformed, weakly to strongly metamorphosed sequence of flyschlike sedimentary and interbedded volcanic rocks that crops out in southeastern Alaska along the west coast of Chichagof, Baranof, and nearby smaller islands. Similar rocks of Late Cretaceous age, including the Shumagin Formation, Kodiak Formation, Valdez Group, and part of the Yakutat Group, are present along the Gulf of Alaska margin and together comprise an extensive accretionary flysch terrane (Plafker and others, 1977) deposited as slope, fan, and basin-plain deposits in an oceanic trench setting (Nilsen and Moore, 1979). These rocks form part of an upper Mesozoic subduction complex that extends along the entire west coast of North America (Jones and others, 1978).

The Sitka Graywacke has been regionally metamorphosed to zeolite (laumontite), prehnite-pumpellyite, or locally, lower greenschist facies. More than half of the exposed rocks have been thermally upgraded to albite-epidote hornfels and hornblende hornfels facies by Tertiary granitoid intrusions (Loney and others, 1975). Texturally, the contact metamorphic equivalents of the Sitka Graywacke are banded hornfels, semischist, schist, and amphibolite that generally retain no relict sedimentary structures. Contact metamorphic effects are strongest on southern Baranof Island, Kruzof Island, northern Chichagof Island, and Yakobi Island, leaving an irregularly shaped belt of very low grade regionally metamorphosed rocks that extends from near Sitka northward to Portlock Harbor on Chichagof Island. The Sitka Graywacke within this belt is a sedimentary melange or broken formation (Hsu, 1968) characterized by pervasive, ductile deformation, rotated strata, and angular tectonic blocks. This deformation precludes measurement of continuous stratigraphic sections.

During the summers of 1977 and 1978, turbidites of the Sitka Graywacke were studied primarily along the western, embayed coastline of Chichagof Island. The rocks in this area are well exposed and affected only by thermal metamorphism. The facies nomenclature used here is that of Mutti and Ricci Lucchi (1972). We recognize three distinct facies associations: middle-fan, inner-fan, and slope. The term "fan" is used to indicate the zone of sedimentation between the base of the slope and the abyssal floor, rather than a necessarily fan-shaped accumulation of sediment characterized by an outward radiating sediment dispersal pattern.

The middle-fan facies association is the most widespread in the Sitka Graywacke of western Chichagof Island (fig. 56). It consists mostly of thick-bedded to massive facies A and B sandstone with thin interbeds of facies D and E sandstone and mudstone.

Facies A and B comprise 10 to 20 percent of the rocks of the middle-fan facies association and consist of medium- to coarse-grained sandstone with rare mudstone interbeds. Thickness is variable but is generally measured in meters or tens of meters. Locally, a crude parallel stratification is visible and probably represents amalgamation (the successive accumulation of sandstone intervals without interbedded mudstone). Sandstone:shale ratios are very high (generally greater than 100:1), and Bouma sequences are absent. The basal contacts of the massive sandstone with the underlying facies D and E deposits are generally sharp and locally channelized. Mudstone rip-ups are common and are generally concentrated near the base of sandstone units. Diagnostic sole marks are rare, and dish structure has not been observed. We interpret facies A and B to be channel-fill deposits and overbank splays associated with infrequent large-volume turbidity currents.

Facies D and E comprise 80 to 90 percent of the rocks of the middle-fan facies association and consist of thinly interbedded sandstone and mudstone. The thickness of one sandstone-mudstone unit is generally less than 10 cm and is typically about 3–5 cm. Sandstone:shale ratios are generally between 1:1 and 4:1 but can be as high as 15:1. Where recognizable, Bouma sequences are generally complete (Ta-e) or contain only the upper parts (base cut-out, Tb-e or Tc-e). The sandstone intervals are typically graded at the base with sharp planar lower contacts and locally distinct wavy upper contacts. Basal sedimentary features are not common, and flute casts were observed at the base of only three beds; however, it is difficult to distinguish primary sedimentary features on the soles of beds from those produced by compaction and deformation. We interpret facies D and E turbidites of the Sitka Graywacke to represent middle-fan deposition on levees and interchannel areas where channels are relatively small and turbidity currents are not well confined.

The inner-fan facies association crops out on the west side of Khaz Peninsula, Klokachef

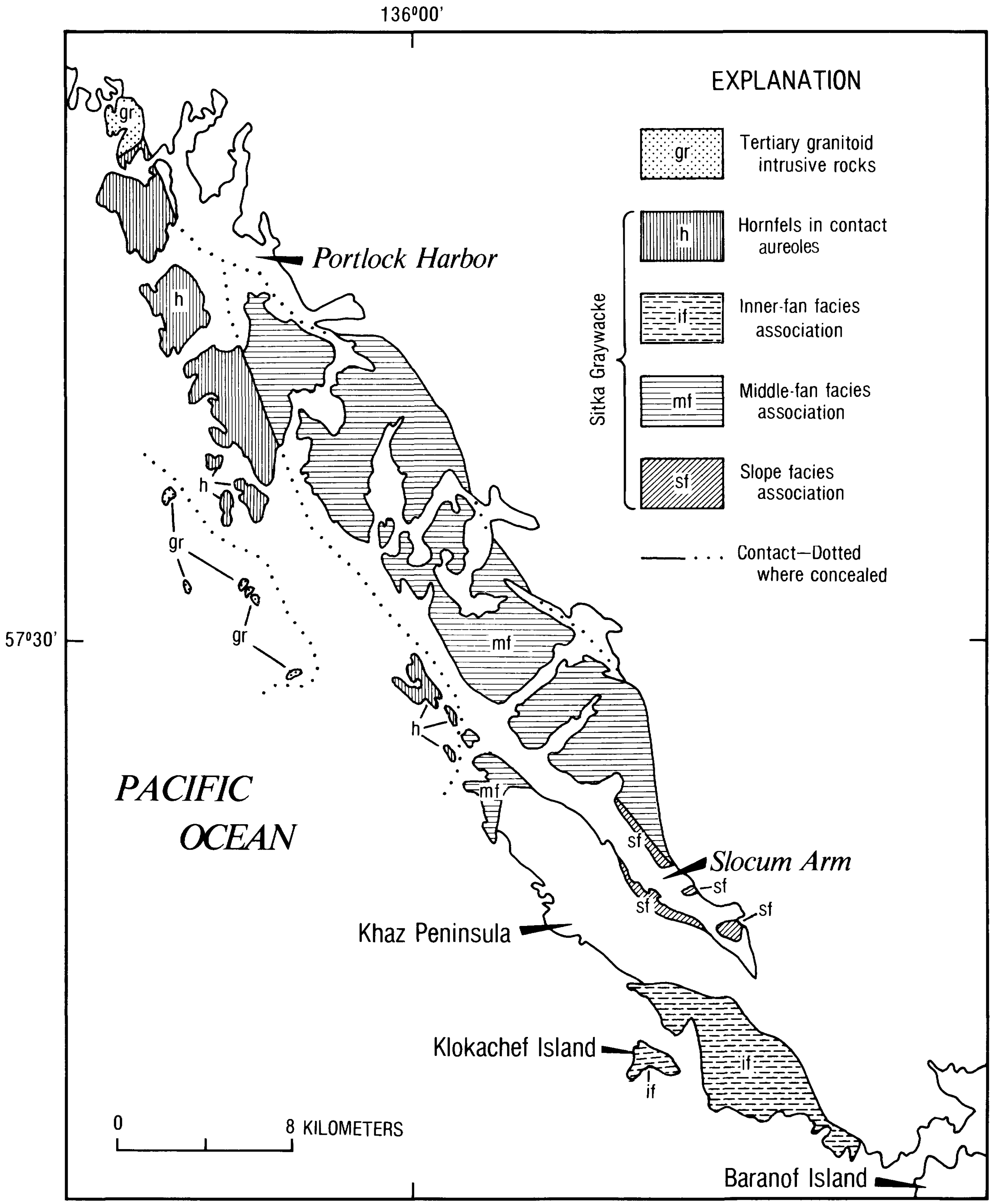

FIGURE 56.—Turbidite facies associations of Sitka Graywacke, western Chichagof Island. (Geology in part from Loney and others, 1975.)

Island, and northern Baranof Island (fig. 56); it includes the type area of the Sitka Graywacke near Sitka on Baranof Island. It is characterized by thick-bedded to massive sandstone (facies A and B) and massive conglomerate and pebbly sandstone (facies A).

Facies A and B comprise about 95 percent of the rocks of the inner-fan facies association and are similar to facies A and B described above. Facies A conglomerate is a volumetrically minor constituent of the inner-fan facies association. Beds range in thickness from a few meters to several tens of meters. The upper contact is either sharp or gradational into massive sandstone; the basal contact is characteristically sharp and locally channelized. Internally, the conglomerate is stratified and locally graded (organized conglomerates: facies A2 of Walker and Mutti, 1973). Clasts rarely exceed 25 cm in length. Sandstone:shale ratios are extremely high and the Bouma sequence is generally not applicable to the beds. We interpret facies A to be channel lag deposits associated with laterally accreting meandering channels.

The slope facies association crops out along both sides of Slocum Arm and includes some metasedimentary deposits of the Khaz Formation of the Kelp Bay Group (Loney and others, 1975) (fig. 56). The slope facies association contains hemipelagic mudstone (facies G), thin interbeds of siltstone and mudstone turbidites (facies D), and redeposited strata (facies F).

Facies G and D consist of thin-bedded siltstone and mudstone turbidites interbedded with hemipelagic mudstone. Sandstone:shale ratios are very low, generally less than 1:10, but the ratio of graded mudstone turbidites to ungraded mudstone is about 1:1. The turbidite intervals are discontinuous over distances of 10 to 15 m and have sharp bases and tops. Because facies G and D are fine grained, they are generally more highly deformed than strata of other facies. Internal sedimentary structures, trace fossils, and sole markings are rarely preserved. Te, Td-e, and Tc-e Bouma sequences can be observed locally. We interpret facies G and D beds to represent deposition of pelagic and hemipelagic sediment on the slope.

Facies F consists of chaotic beds subjected to submarine landsliding by processes of flow, fall, slump, and slide. Because the Sitka Graywacke is characterized by a melangelike fabric, it is commonly difficult to distinguish between syndepositional and postdepositional gravity-induced deformation and ductile tectonic deformation of unlithified strata. We assign chaotic strata to facies G only if they show clear evidence of having been previously deposited elsewhere. The principal criterion used to make this distinction is the nature of the disrupted strata compared to the nature of the host rock. For example, on the east side of Khaz Peninsula, *Buchia*-bearing, medium-grained sandstone with shallow-marine trace fossils occurs in blocks of varying size (tens of meters) in an interbedded facies G and D sequence with deep-marine trace fossils. The shallow-marine facies sandstone is clearly foreign to the surrounding fine-grained turbidites and was probably redeposited by submarine landsliding.

The slope, inner-fan, and middle-fan facies associations may not be part of a single deep sea fan complex or depositional system. Thin sections stained for potassium feldspar and plagioclase and rock slabs stained for potassium feldspar (H. C. Berg, written commun., 1979) show that the inner-fan facies contains primary first-cycle plutonogenic sandstone rich in potassium feldspar, whereas the middle-fan facies association contains chiefly first-cycle volcanogenic sandstone deficient in potassium feldspar. Alternatively, the depositional system may have prograded through time, the middle-fan facies association derived from a coeval volcanic terrane having been succeeded by deposition of the inner-fan facies association derived from the unroofing plutonic basement. The slope facies association may contain sediments derived from both volcanic and plutonic sources.

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The Tertiary Kuiu-Etolin volcanic-plutonic belt, southeastern Alaska

By David A. Brew, Henry C. Berg, Robert P. Morrell, Ronald A. Sonnevil, Susan J. Hunt, and Carl Huie

Recent field studies in the Petersburg 1:250,000-scale quadrangle suggest that a 200-km-long by 30-km-wide volcanic-plutonic belt of Tertiary age extends from central Kuiu Island on the northwest to Etolin Island on the southeast (fig. 57). The belt, which is inferred to be 20–25 m.y. old, is at an angle to most regional structural trends and may contain anomalously high amounts of tungsten and other elements.

The Tertiary volcanic rocks in the belt have long been known (Wright and Wright, 1908; Buddington and Chapin, 1929; Muffler, 1967) and generally have been interpreted to be part of a Tertiary basin extending from Admiralty Island on the north to Zarembo Island on the south (Miller and others, 1959; Brew and others, 1966). The rocks in the basin are considered Eocene to Miocene(?) in age (Lathram and others, 1965). The available evidence suggests that the basin consists of two main parts, a northern section consisting largely of andesitic flows with some intercalated continental sedimentary rocks and a southern part consisting of a complex of dikes, sills, flows, and stocks with locally important intercalated continental sedimentary rocks. This southern part is the subject of this report.

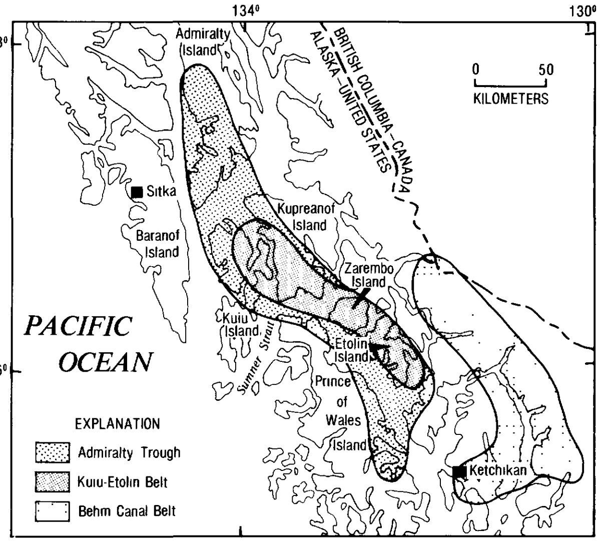

FIGURE 57.—Location of Tertiary Admiralty Trough (after Brew and others, 1966, fig. 8–12) and Kuiu-Etolin and Behm Canal belts (from Brew and Morrell, 1979), southeastern Alaska.

Detailed compositional data are not yet available nor has field mapping been completed in the southern part of the Tertiary belt, but the general features of the volcanic-intrusive complex are known well enough to warrant preliminary description. Perhaps the most obvious feature is the belt's N. 60° W. trend (fig. 57). Almost all of the sedimentary and metamorphic rock units in southeastern Alaska strike consistently north-northwest (Beikman, 1975), as do the other intrusive rock belts (Brew and Morrell, 1979) and the tectonostratigraphic terranes (Berg, Jones, and Coney, 1978). The cause of this discordance is not known, but the belt postdates all of the other features just mentioned.

A poorly understood volcanic-plutonic mass that intrudes the Silurian Bay of Pillars Formation marks the west end of the belt on central Kuiu Island. The central part of the mass is a hypabyssal-looking (epidote)-(magnetite)-(biotite)-hornblende diorite, quartz diorite, granodiorite, and quartz monzodiorite stock. It is surrounded by volcanic breccia, flows, dikes, sills, and volcanic wacke(?) of silicic(?) to intermediate composition. Eastward and on the islands in Sumner Strait, this outer part consists mainly of intermediate flows and dikes but also includes some small rhyolite plugs, gabbro sills, and some continental sedimentary rocks. Beyond Sumner Strait and south of Kupreanof Island is Zarembo Island, which has a very confusing silicic to intermediate dike and flow complex with minor intercalated fossiliferous sedimentary rocks and at least one miarolitic granite plug. Southeast of Zarembo Island a fairly large body of miarolitic biotite granite underlies much of northern Etolin Island. Preliminary aeromagnetic interpretation strongly suggests that the belt does not connect with the Behm Canal belt (fig. 57), another Tertiary plutonic belt to the southeast (Brew and Morrell, 1979).

The age of the Kuiu-Etolin belt is inferred on the basis of 1) the intercalated fossiliferous continental sedimentary rocks of Eocene to Miocene age in the north, and 2) the lithologic similarity between the miarolitic granitic rocks and isotopically dated Oligocene and (or) Miocene granites of the Behm Canal belt (Berg, Elliott, and others, 1978). These latter granites contain molybdenum and perhaps uranium resources. Very preliminary synthesis of the available stream-sediment and bedrock geochemical data suggests that the Kuiu-Etolin belt may locally contain anomalously high concentrations of tungsten, zinc, and molybdenum.

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Reconnaissance engineering geology and geologic hazards of the Petersburg area, southeastern Alaska

By L. A. Yehle

A reconnaissance engineering geology report on the city of Petersburg and vicinity (Yehle, 1978) emphasizes the potential effect of geologic hazards on the community. Petersburg is built on a peninsula of low relief that contrasts sharply with the rugged mountains of the remainder of Mitkof Island. Bedrock on the peninsula consists of relatively firm metamorphic rock, chiefly phyllite of Middle(?) Jurassic to Early Cretaceous age, that lies at comparatively shallow depth beneath firm to soft surficial deposits. Inland from the present shores and minor deltas of the Petersburg peninsula, glacial and glaciomarine stony diamicton forms the prevalent surficial deposit and, in many places, grades laterally to stone-free silt-clay; thickness varies widely and probably averages 15 m. Locally, remnants of emerged sandy deltaic and shoreline deposits cap the diamicton and marine silt-clay and bedrock. Ubiquitous peat deposits, possibly averaging 2.5 m in thickness, cover most surficial deposits and bedrock.

Glacier ice of the last major glaciation probably melted from Petersburg and nearby areas about 13,000 to 12,000 years ago. Even after the glacier disappeared, land depression resulting from the ice load continued to affect the area for several thousand years, as indicated by the mantle of marine, deltaic, and shoreline deposits at altitudes as much as 75 m.

Marine fossils from several locations on Mitkof Island and Wrangell Island, a short distance to the southeast, have been dated by radiocarbon methods (Lemke, 1974). Among the carbon-14 dates of these fossils, the highest and oldest is approximately 12,400 years old (U.S. Geological Survey W-1734; R. W. Lemke, unpub. data, 1965). On the basis of measurements made between 1910 and 1960 (Hicks and Shofnos, 1965), land in the Petersburg area is rising with respect to sea level at a rate of about 0.4 cm/yr.

The latest major tectonic events that directly affected the Petersburg area probably occurred in latest Tertiary time. Current major and moderate tectonic activity apparently is confined to areas offshore from southeastern Alaska defined by the Queen Charlotte and adjoining fault segments, a minimum of 170 km distant from Petersburg. Earthquakes of as much as about Richter magnitude 8 are possible along these faults because such shocks have occasionally occurred in historic times.

Geologic hazards affecting the Petersburg are minor and include, most importantly, the secondary effects of earthquakes along the Queen Charlotte fault. Since its founding in 1897, Petersburg has undergone only very minor earthquake damage; the most serious was during the magnitude 7.1 earthquake of October 24, 1927, when several windows were broken. Among secondary effects that might occur during any future, major earthquake, ground shaking and liquefaction would be the most important. These effects would be most severe on the thickest organic deposits, artificial fill, and on the softer silt and clay.

The probability of severely damaging water waves in Petersburg harbor is small; waves about 1 m high were experienced as a result of the 1964 Alaska Good Friday earthquake. The waves probably were the result of seismic seiching. Higher waves might be induced by focusing of waves reflected from the shoreline or generated by earthquake-induced subaerial or subaqueous landslides.

Other geologic hazards in the Petersburg area include waves and landslides not generated by earthquakes, minor landslides along steeper slopes in the Petersburg area, and icebergs discharged by tidal glaciers on the mainland. From time to time these icebergs move along the channels near Petersburg and disrupt some fishing and shipping operations.

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Ground-water data from molybdenum resource area, Keta River basin

By L. L. Dearborn and G. O. Balding

During a ground-water reconnaissance study, down-hole geophysical and water-quality data were collected in two coreholes in bedrock located in an area with potential for molybdenum development east of Ketchikan, Alaska. Data consisted of geothermal, natural gamma, and gamma-gamma logs. Flow velocities were measured using a brine injector. One of the two coreholes was discharging ground water at the surface. The initial discharge rate of 0.9 L/s eventually dropped to 0.1 L/s.

The geothermal log of the flowing corehole indicated three distinct deflections in the thermal gradient. On the natural gamma and gamma-gamma logs, zones less dense than those immediately above and below indicated fracture zones and coincided with the deflections on the geothermal log. Subsequent brine injection measurements near those deflection points indicated that ground-water flow velocities ranged from 0.03 to more than 1.10 m/s in the corehole.

For the nondischarging corehole there were no deflections on the geothermal log even though the gamma-gamma log indicated two possible fracture zones. Subsequent brine injection measurements confirmed the suspected static conditions.

Specific conductance ranged from 185μmhos in the nonflowing corehole to 1,200μmhos in the flowing corehole. Water-quality analyses showed that water from the nonflowing corehole was $CaCO_3$ type, whereas that from the flowing corehole was a $CaSO_4$ type.

Surface-water data from molybdenum resource area, Keta River basin

By G. O. Balding

In 1978 water-discharge, suspended-sediment, and water-quality data were collected at seven sites on streams east of Ketchikan, Alaska, to delineate present hydrologic conditions in an area with known molybdenum-development potential. Recording stations were installed near Ketchikan on White Creek and Keta River to obtain a continuous record of stream discharge, specific conductance, and water temperature. For White Creek the mean daily unit discharge ranged from 20.6 to 293 (L/s)/km^2; conductivity ranged from 27 to 72μmhos; temperature ranged from 0.0 to 8.5°C; and pH ranged from 6.0 to 6.4. Measured suspended-sediment concentration ranged from 0 to 0.3 mg/L. For Keta River the mean daily unit discharge ranged from 11.2 to 1,410 (L/s)/km^2; conductivity ranged from 9 to 36μmhos; temperature ranged from 0.0 to 14.5°C; and pH ranged from 6 to 6.4. Suspended-sediment concentration ranged from 0 to 2.3 mg/L.

OFFSHORE ALASKA

Geologic and geophysical cruise across the outer Bering continental margin

By Alan K. Cooper and Michael S. Marlow

The Bering continental margin extends 1,300 km northwest from the Aleutian ridge to Cape Navarin, Siberia (fig. 58). The outer margin, which includes the outer continental shelf, continental slope, Umnak Plateau, and the continental rise, is cut by several immense submarine canyons. Large sediment-filled basins separated by basement ridges lie beneath most of the outer part of the continental shelf. These basins are large structures that have subsided and acted as sediment traps since Mesozoic or early Cenozoic time. Thick accumulations of Cenozoic strata are also found along sediment-draped parts of the continental slope and beneath the abyssal Aleutian Basin. The transition from continental crust, which is incised by deep shelf basins, to oceanic crust, which is covered by thick sediment, occurs beneath the continental slope.

As part of an ongoing program for investigating the geology and regional tectonic framework of the Bering Sea, a combined geologic and geophysical cruise across the outer margin was conducted aboard the U.S. Geological Survey research vessel *S. P. Lee* during July 1978. The primary objective of the cruise was to collect rock samples from the acoustic basement and overlying sedimentary section to gain a better understanding of the geologic history of the continental margin. A second objective was to conduct a detailed seismic refraction survey over Umnak Plateau to determine the velocity structure of the underlying crustal rocks (continental or oceanic ?). During the cruise several thousand kilometers of seismic reflection, gravity, magnetic, high-resolution seismic, and bathymetric data were recorded. In addition, 28 seismic refraction stations (sonobuoy) and 30 dredge sites were occupied (see fig. 58). Rock samples were recovered at 20 sites, only two of which yielded fossils. Foraminifers were identified by Paula Quinterno; megafossils were identified by David L. Jones.

Rocks dredged from sites along the edge of the continental slope (1,500–2,800 m of water) include a wide range of diatomaceous mudstone, volcanic and tectonic breccias, and indurated sandstone. The oldest rocks are shallow-water lithic sandstones of Late Jurassic age that were recovered from nine sites in the acoustic basement complex along the segment of the continental margin that extends 550 km northwest from Pribilof Canyon. The Late Jurassic megafossil *Buchia rugosa*, found in quantity in one dredge haul, is a shallow water pelecypod that is found in the Naknek Formation of the Alaska Peninsula to the southeast and in the Koryak Mountains to the northwest. Preliminary lithologic and petrographic examination of the sandstones indicates that the rocks are of similar age to but have a much higher lithic fraction than those on the Alaska Peninsula. The difference in lithology suggests a different source terrane for the two areas during Late Jurassic time. Geophysical data indicate that Jurassic rocks exposed on the Peninsula are structurally connected to the same age rocks dredged along the margin, west of the Pribilof Islands (Marlow and others, 1977).

Younger rocks overlying acoustic basement primarily consist of diatomaceous mudstone ranging in age from Eocene to Holocene. The mudstone rests unconformably on the Upper Jurassic acoustic basement. Other rocks above the accoustic basement are barren of fossils and include volcanic sandstone and breccia, muddy limestone, andesitic tuff, and fault breccia. Reflection profiles across the sediment-draped areas of the margin indicate that the mudstones

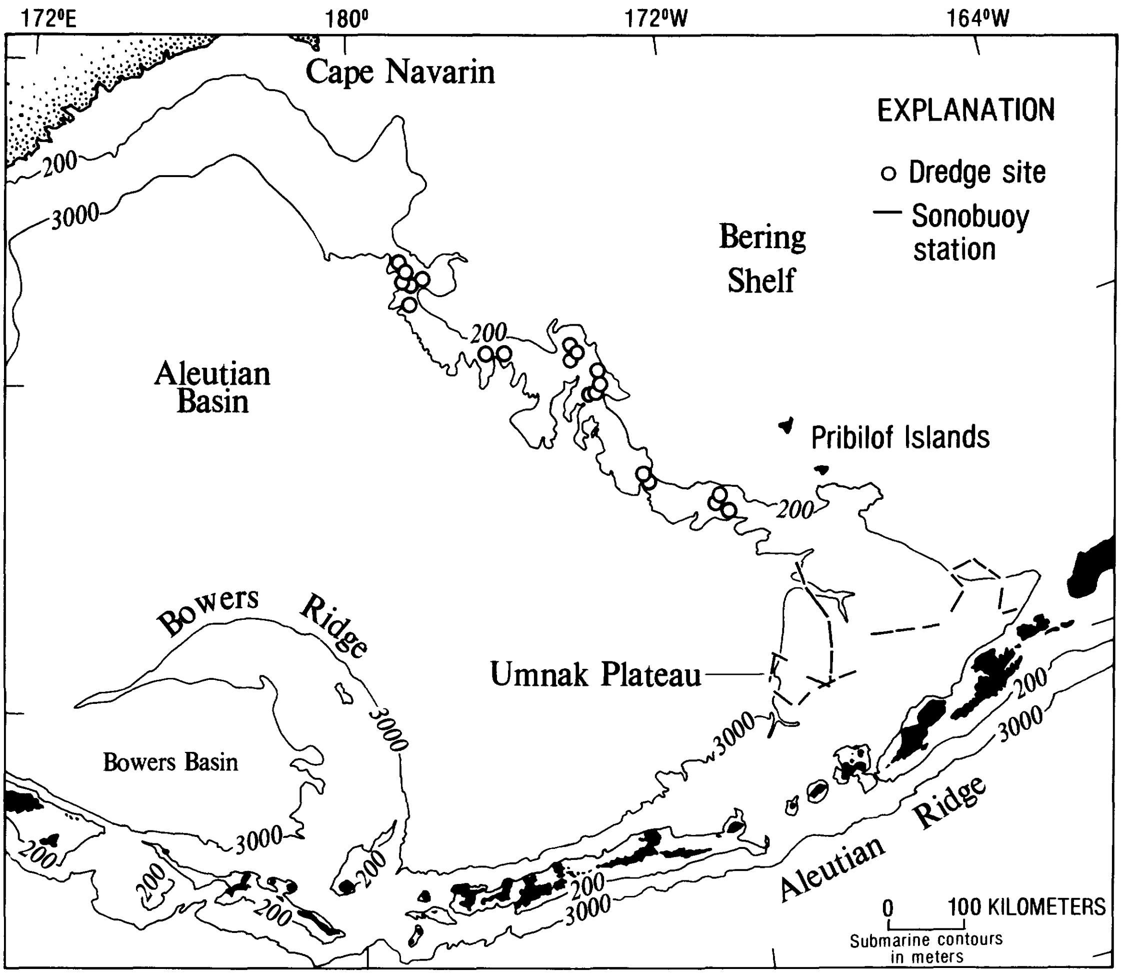

FIGURE 58.—Bathymetric map showing dredge sites and sonobuoy stations, outer Bering continental margin.

can be traced from the upper continental slope down to the abyssal Aleutian Basin. At the base of the continental slope, only the upper half of the 7- to 10-km-thick sedimentary section may be younger than early Oligocene age. The age of the deeper rocks may be as old as Mesozoic.

Previous theories on the tectonic evolution of the Bering Sea implied that the continental margin should be underlain either by deformed Mesozoic trench deposits or by continental slope deposits that were structurally accreted to the margin by oblique convergence between the Kula and North American plates. However, rocks dredged from the margin now indicate that a belt of shallow-water Upper Jurassic sandstone underlies the outer Bering margin between southwestern Alaska and eastern Siberia. This belt subsided in early Tertiary time to form the existing Bering continental margin. Collapse of the outer margin is greater than 2–3 km and is confined to a narrow (20–25 km) zone beneath the continental slope; parts of the outer continental shelf have subsided more than 10 km to form the deep subshelf basins.

Umnak Plateau, a deep-water (2,000 m) marginal plateau, lies at the junction of the Aleutian Ridge and the Bering margin. At this junction, the Aleutian ridge trends southwest and is underlain by early Cenozoic igneous and volcaniclastic rocks, whereas the outer Bering margin trends northwest and is underlain by a foldbelt of sedimentary rocks of Mesozoic age. The time (Cenozoic or Mesozoic ?) and mode of origin of the marginal Umnak Plateau are enigmatic because of its structural location.

Preliminary analysis of seismic sonobuoy data indicates that the velocity structure of Umnak Plateau is similar to that of the oceanic crust beneath the Aleutian Basin and is different from the continental crust beneath the Bering shelf. The transition from oceanic to continental crust occurs under the continental slope on the landward, rather than the seaward, side of the plateau. The location of this transition may mark the edge of the ancient Mesozoic continental margin. The thick (3–4 km) sedimentary section beneath the plateau can be divided into four velocity units that are similar to units found beneath the Aleutian Basin. The deeper velocity units drape over the edge of the plateau and continue into the basin. The draping of deep velocity horizons and the oceanic-type crustal velocities beneath the plateau suggest that the plateau is underlain by uplifted oceanic crust. This uplift may reflect either compressional buckling or thermal expansion of oceanic crust; the uplift may have occurred in Paleogene time in response to a change in the underthrust direction of the Pacific plate beneath the Aleutian arc.

Wide-angle reflection velocity data indicate that a thin (0.5–1 km), seismically opaque layer (v = 3.5 – 4.3 km/s) lies directly above acoustic basement (v = 5.2 – 5.7 km/s). This layer is found throughout the plateau and in earlier studies was thought to be acoustic basement. The variable thickness of the layer and the local thickening near diapirs both suggest that this opaque layer may be a mobile mudstone or shale unit. Mudstone from this layer may form the core of the diapirs that are prevalent throughout the plateau. Mobilization of this mudstone or shale may have been in response to subplateau magmatism and heating during episodes of magmatic activity along the Aleutian arc.

Umnak Plateau, in contrast to other marginal plateaus, therefore, appears to have formed by uplifting of oceanic crust rather than by subsidence of continental crust. The contemporaneous uplift of the plateau and the regional subsidence of the outer continental margin seem contrary. However, in the region near Umnak Plateau, a more complex model that encompasses the thermal and structural history of both the Aleutian Ridge and the Bering margin may be necessary to explain the observed relations.

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Potassium-argon ages and geochemistry of basalt dredged near Saint George Island, southern Bering Sea

By Garey L. Simpson, Tracy L. Vallier, James E. Pearl, and Florence Lee-Wong

Two potassium-argon dates from basalt dredged approximately 17 km south of Saint George Island (fig. 59) indicate that extrusive activity in the southern part of the Pribilof basalt province lasted until at least 0.8 m.y. ago (table 16), which is more recent than previously reported (Cox and others, 1966).

Argon measurements were made using conventional isotope dilution techniques (Dalrymple and Lanphere, 1969). Mass analysis was performed with a Nier-type 6-inch-radius 60° sector mass spectrometer. Potassium values were established by flame photometry. Two potassium values were determined for each sample. The decay constants used for ^{40}K are $\lambda_e = 0.572 \times 10^{-10}$/yr and $\lambda_b = 4.962 \times 10^{-10}$/yr. X-ray fluorescence spectroscopy was provided by Neil Elsheimer and Scott Morgan (USGS Branch of Analytical Laboratories, Menlo Park, Calif.).

Both samples are medium-gray fine-grained vesicular basalt. Sample DR5-8 has glomeroporphritic plagioclase and olivine in a weakly pilotaxitic groundmass including augite, magnetite, and trace amounts of palagonite. Sample DR5-34 is finer grained and subophitic and contains glomeroporphyritic plagioclase and olivine. Euhedral magnetite, apatite, palagonite, enstatite(?), and an unknown micaceous mineral constitute the remainder of the specimen. Major oxide geochemistry and mineralogy are given in table 17. The rocks are alkalic (fig. 60) and are similar to other basalts from the Pribilof Islands (Florence Lee-Wong, unpub. data, 1979).

The young potassium-argon dates extend the time of basalt eruptions in the southern part of the Pribilof basalt province from 1.6–2.2 m.y. ago (Cox and others, 1966) to 0.8–2.2 m.y. ago. D. M. Hopkins (oral commun., 1979) reported a youngest age of 0.95 m.y. for a recently analyzed basalt from Saint George Island, which indicates that the southern part of the Pribilof basalt province was active through most of the Pleistocene epoch. In contrast, basalts from Saint Paul Island show that volcanic activity in

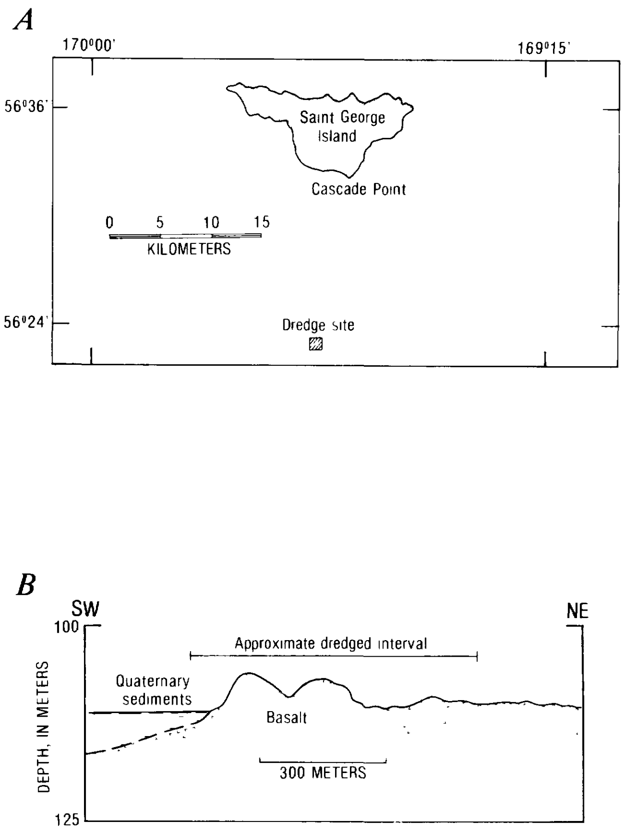

FIGURE 59.—Dredge site near Saint George Island. *A*, Location of dredge site. *B*, Sketch of seismic reflection profile across dredged outcrop.

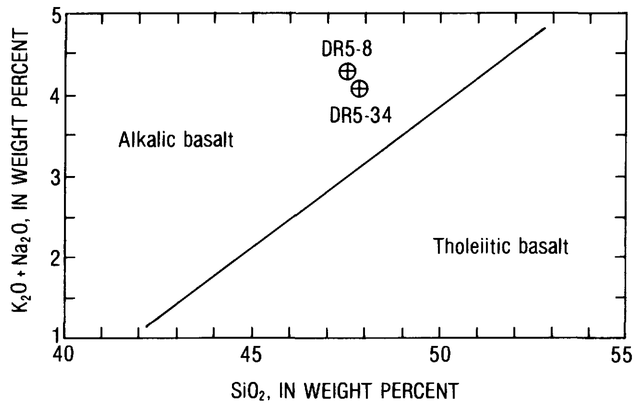

FIGURE 60.—Alkali-silica diagram (after MacDonald and Katsura, 1964) showing alkalic nature of basalt samples.

the northern part of the Pribilof basalt province has continued almost to the present (Cox and others, 1966).

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Seaward extension of the Fairweather fault

By Paul R. Carlson, George Plafker, Terry R. Bruns, and William P. Levy

The seismically active Fairweather fault (Tocher, 1960; Page, 1969; Plafker and others, 1976) has been mapped from Yakutat Bay to the shoreline of Palma Bay (Plafker, 1967), and numerous authors have speculated on the seaward extension of this major structural feature (St. Amand, 1957; Grantz, 1966; Stoneley, 1967; Plafker and others, 1978; von Huene and others, in press). Some widely spaced seismic profile lines made prior to 1978 across the shelf

TABLE 16.—*Analytical data for potassium-argon age determinations*

Sample No.	K_2O (wt. percent)	^{40}Ar rad (moles/gram)	^{40}Ar rad/^{40}Ar total (100 x)	Calculated age (10^6 years)
DR5-8	0.781 .784	9.42×10^{-13}	13.32	0.836 ± .08
DR5-34	.757 .758	8.46×10^{-13}	8.93	.774 ± .08

TABLE 17.—*Major oxide geochemistry and modal analysis*

Major oxide geochemistry		
Oxide	DR5-8	DR5-34
SiO_2	48.52	48.95
Al_2O_3	15.04	14.99
Fe_2O_3	3.35	3.20
FeO	8.03	8.45
MgO	7.76	8.50
CaO	8.99	9.09
Na_2O	3.65	3.47
K_2O	.89	.80
TiO_2	1.85	1.89
P_2O_5	.45	.35
MnO	.14	.15
Total	98.67	100.09
Modal analysis (500 count)		
Mineral		
Plagioclase	47.2	53.6
Olivine	10.8	17.3
Magnetite	13.0	9.0
Palagonite	3.6	2.2
Enstatite	.2	1.0
Augite	25.2	16.7
Apatite	----	.2
Total	100.0	100.0

south of Palma Bay (Bruns and Bayer, 1977; Molnia and others, 1978; von Huene and others, in press; P. R. Carlson, B. F. Molnia, and W. P. Levy, unpub. data, 1976) showed faulting and submarine scarps that appeared to line up with the onshore trace of the Fairweather fault; however, line spacing was inadequate to permit mapping of this significant strike-slip fault.

During 1978 R/V *Sea Sounder* and R/V *S. P. Lee* made cruises totaling 1,500 km of seismic lines across the shelf southeast of Palma Bay (fig. 61). A major objective of cruise S–5–78 was to trace the offshore extension of the Fairweather fault. To accomplish this objective, three seismic reflection profiling systems (80 kiloJoule sparker, 500 Joule minisparker, and 3.5 kiloHertz transducer) were used on a fairly tight line spacing on the shelf. Seven more widely spaced crossings of the continental margin between Chatham Strait and Cross Sound were made during cruise L–3–78, using a multi-channel seismic system, a 500 Joule minisparker, and a 3.5 kiloHertz transducer. Features interpreted as possible faults or fault zones found on all seismic lines included well-defined submarine scarps, offset, broken, and distorted subbottom reflectors, and abrupt changes in reflector attitudes. Because of the strike-slip nature of the fault system, no measurements of offset were obtained, and not all characteristics listed above were found on each line.

The seismic lines show evidence for the existence of two fault traces (fig. 61). On lines closest to Icy Point, the eastern fault trace, which is less well defined than the western trace, appears to trend directly into the Fairweather fault. The trace west of Icy Point seems to line up with a fault that has been inferred, on the basis of structural features along the shore, to lie just offshore along the coastline at least as far northward as Lituya Bay (Plafker, 1967; Bruns, 1979). The strike of the fault shifts 25° as the fault passes offshore near Palma Bay. The separation between these two subparallel fault traces varies from 6 km near Icy Point to about 12 km off southern Chichagof Island. These two traces extend across the shelf in a south-southeasterly direction for 225 km where they appear to merge on the upper continental slope just southwest of Sitka. From this point, our data indicate that the remaining fault trace is present near or seaward of the shelf break at the 200-m isobath and extends along the same trend for at least another 75 km. Yet another fault that lies east of and parallel to the 200-m isobath extends for about 40 km southeast of the Sitka 1972 epicenter. This fault trace could possibly connect with the easternmost trace of the Fairweather fault; however, additional seismic lines would be needed in the area west-southwest of Sitka to prove this connection.

Widely spaced multichannel lines suggest that recent sediments have not been faulted seaward of the continental shelf from Icy Point to the position southwest of Sitka where the two shelf fault traces appear to merge. Southeast of this area, however, features suggestive of faulting are present on the continental slope or near the base of the slope.

The mapped fault traces are complex, consisting of a number of splays or slivers. At several places where the fault bifurcates or splays, the minor trace forms an arc and appears to rejoin the major trace. An exception, however, is the northernmost bifurcation in the Fairweather fault extension. About 20 km southeast of Palma Bay, the Fairweather fault undergoes a major bifurcation with a branch fault splitting off southeastward at an angle of about 35°. This branch fault trends toward Lisianski Inlet where it may connect with the Peril Strait fault (Loney and others, 1975).

The offshore faults vary greatly in appearance on seismic profiles from line to line. Some records show well-defined scarps on the seafloor with relief of 25–40 m. Other crossings of the fault trace show no surface offset but commonly show broken reflectors or abrupt changes in bedding (reflector) attitudes that are best explained by faulting. Of the two traces, the western one is better defined and considerably straighter than the eastern one. Most unequivocal evidence for Holocene displacement, as manifested by seafloor displacements, is on this western trace. In most crossings of the fault trace, where seafloor offsets are well displayed, the sense of movement is northeast side down, showing the same sense of vertical displacement as occurred along the onshore Fairweather fault during the 1958 Lituya Bay earthquake (Tocher, 1960). The more sinuous or eastern trace may be an inactive or relatively less active strand of the fault system; however, several of the profiles also showed some seafloor offset along this trace.

The epicenters of the 1972 Sitka and 1958 Lituya Bay earthquakes are plotted on figure 61. The 1958 epicenter plots just south of Palma Bay between the two fault traces (Sykes, 1971); the earthquake was accompanied by displacement on the Fairweather fault for about 300 km

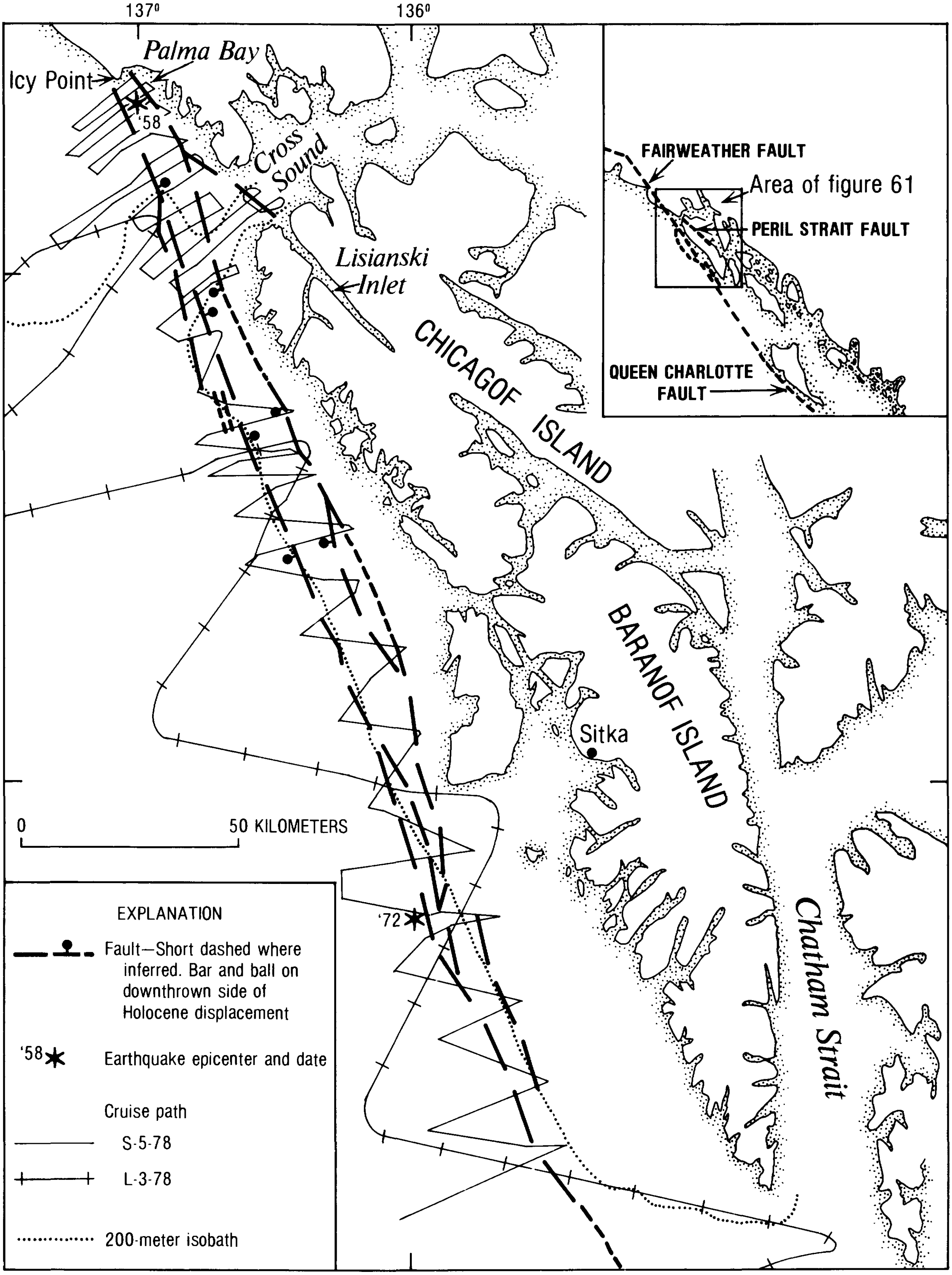

FIGURE 61.—Sketch map of southeastern Gulf of Alaska showing seaward extension of Fairweather fault system and seismic reflection track lines.

northwest of Palma Bay (Plafker and others, 1978). The 1972 epicenter, about 2 km west of the outermost fault trace, and its focal region (Page, 1973) virtually coincide with the active trace mapped on figure 61.

The data suggest the westernmost of these continental margin fault traces connects the active Fairweather and Queen Charlotte faults although such a connection implies an apparent complex offset of close to 6 km between the onshore and submarine fault traces in the vicinity of Palma Bay.

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Unusually well preserved and diverse Eocene foraminifers in dredge samples from the eastern Gulf of Alaska continental slope

By Weldon W. Rau

Two samples dredged from outcrops on the continental slope in the eastern Gulf of Alaska contain unusually well preserved and diverse assemblages of Eocene foraminifers. The samples (numbers S5–78–EG–43 and 44) were collected during 1978 by the R/V *Sea Sounder* from an area roughly 120 km southwest of Yakutat as part of the U.S. Geological Survey's program to evaluate the petroleum potential of the outer continental shelf in the vicinity of Lease Sale 55, planned for mid-1980 (Plafker and others, 1979, fig. 62). This paper lists the foraminiferal fauna in the two samples and discusses their implications for the age, depositional environment, and correlations of the strata in which they occur.

Sample S5–78–EG–43, dredged from depths of 2,860 m (lat 58° 44.94′ N., long 141° 13.21′ W.) to 1,680 m (lat 58° 44.88′ N., long 141° 8.76′ W.), is a moderately well indurated, light-greenish-gray, waxy, slightly calcareous shale. It is associated in the dredge haul with calcareous silty shale and palagonitized basaltic tuff.

Sample S5–78–EG–43 contains the following foraminifers:

Allomorphina cf. *A. macrostoma* Karrer
Anomalina cf. *A. crassisepta* Cushman & Siegfus
Cibicides spp.

Globiegerina cf. *G. linaperta* Finlay
Globigerina cf. *G. primitiva* (Finlay)
Gyroidina soldanii d'Orbigny
Lenticulina cf. *L. inornatus* d'Orbigny
Lenticulina cf. *L. pseudovortex* (Cole)
Loxostomum applinae (Plummer)
Marginulina subbullata Hantken
Nodosaria latejugata Gumbel
Planularia cf. *P. truncana* (Gumbel)
Praeglobobulimina cf. *P. guayabalensis* Cole
Pseudoglandulina conica (Neugeboren)
Pseudoglandulina cf. *P. inflata* (Bornemann)
Silicosigmoilina californica Cushman & Church
Spiroplectammina cf. *S. directa* Cushman & Siegfus
Spiroplectammina richardi Martin
Tritaxalina colei Cushman & Siegfus
Vaginulinopsis asperuliformis (Nuttall)
Vaginulinopsis vacavillensis (Hanna) (*Mexicana* var. *B.* of Laiming)
Valvulineria jacksonensis welcomensis Mallory

Similar assemblages are well known in marine Eocene strata of California, Oregon, and Washington where they characteristically occur in rocks assigned to either the Penutian Stage or a lower part of the Ulatisian Stage of Mallory (1959). In terms of zones of Laiming (1940), the assemblage characterizes strata assigned to either his C zone or lower B zones. Although most taxa of this assemblage are known to display the above range of stratigraphic occurrence, several are more commonly associated with the older strata within this range, particularly *Loxostomum applinae* and *Silicosigmoilina californica.* Therefore, the foraminiferal evidence may slightly favor a Penutian (early Eocene) age. Independent evidence for an early Eocene age, based on both planktonic foraminifers and cocoliths, has been presented by Poore and Bukry (1979).

The foraminifers suggest middle bathyal to no less than outermost shelf water depths (100–1,000 m) as inferred by the combined occurrence of particularly robust *Lenticulina* and *Vaginulinopsis*, *Allomorphina*, several arenaceous species, and common *Praeglobobulimina.* Optimum depths for the assemblage are perhaps 500–1,000 m.

The benthic taxa generally suggest cool water, particularly the arenaceous species. However, diversity of the assemblage suggests that temperatures were not extreme, and the common occurrence of several species of planktonic foraminifers indicate relatively warm surface temperatures.

The find documents the first Penutian or Ulatisian (early or middle Eocene) foraminiferal fauna reported from surface rocks of either the onshore or offshore Gulf of Alaska. Previously, Penutian/Ulatisian foraminifers had been recorded only in the Middleton Island no. 1 well from a depth greater than 10,000 feet (Rau and others, 1977).

Sample S5–78–EG–44, collected between 1,500 m (lat 58° 45.22′ N., long 141° 8.84′ W.) and 1,270 m (lat 58° 47.53′ N., long 141° 3.14′ W.), is a soft to moderately well indurated, dark-olive-gray, laminated shale with minor glauconite and pyrite. It contains abundant foraminifers, calcareous nannoplankton, dinoflagellates, and siliceous microfossils in addition to a megafauna of abundant fish scales and rare small (<1 cm) thin-walled pelecypods. Associated rocks in the same dredge haul include glauconitic sandstone and a brecciated limestone or calcareous concretion.

Sample S5–78–EG–44 contains the following foraminifers:

Anomalina aff. *A. garzaensis* Cushman & Siegfus
Astacolus cf. *A. crepidula* (Fichtel & Moll)
Bulimina microcostata Cushman & Parker
Dentalina cf. *D. consobrina* d'Orbigny
Epistomina eocenica Cushman & M. A. Hanna
Globocassidulina globosa (Hantken)
Lenticulina cf. *L. coaledensis* (Detling)
Lenticulina welchi (Church)
Planularia cf. *P. markleyana* Church
Praeglobobulimina cf. *P. guyabalensis* Cole
Pullenia eocenica Cushman & Siegfus
Stilostomella bradyi (Cushman)
Uvigerina garzaensis Cushman & Siegfus
Valvulineria jacksonensis welcomensis Mallory
Valvulineria tumeyensis Cushman & Simonson

Strikingly similar assemblages commonly occur in upper Eocene strata of California, Oregon, and Washington where they generally characterize the Narizian Stage of Mallory (1959). Locally, similar assemblages characterize the A–1 zone of Laiming (1940) in California and the *Bulimina schenck-Plectofrondicularia jenkinsi* zone of Rau (1958) in the Pacific northwest. Late Eocene foraminiferal assemblages have been previously recorded from the Gulf of Alaska (Rau and others, 1977), but none of them contains such a diversity of species or is as diagnostic of age. Poore and Bukry (1979) independently assign a similar Eocene age to coccoliths and planktonic foraminifers from samples of dredge 44. The coccoliths suggest an age that spans the presently accepted middle Eocene-upper Eocene boundary, whereas the planktonic foraminifers are more precisely referred to an upper part of the middle Eocene, a position only slightly lower than is suggested by the benthonic foraminifers.

Intermediate to deep water depths are suggested by the association of *Pullenia*, hispid uvigerinids, finely costate buliminids, several species of *Valvulineria*, and a strong representation of uniserial and coiled lagenids. Optimum water depths for such assemblage may have been middle bathyal (500–1,000 m). Water temperatures were probably fairly warm for the depth. The absence of abundant planktonic foraminifers suggests that ocean currents may have been somewhat restricted.

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Preliminary report on Eocene calcareous plankton from the eastern Gulf of Alaska continental slope

By Richard Z. Poore and David Bukry

A program of sampling the rocks of the continental slope in the eastern Gulf of Alaska is being carried out by the U.S. Geological Survey to evaluate the petroleum potential of the outer continental shelf (Plafker and others, 1978, 1979). Samples from three dredge hauls taken about 120 km southwest of Yakutat by the R/V *Sea Sounder* in 1978 contain coccoliths and planktic foraminifers that are diagnostic of the early and middle Eocene. These samples represent the best record to date of Eocene calcareous plankton from the high-latitude eastern North Pacific, and our purpose is to report the results of our preliminary examination of the coccoliths (D. Bukry) and planktic foraminifers (R. Z. Poore).

Dredge hauls S5–78–EG–43, S5–78–EG–44, and S5–78–EG–45 were made in the vicinity of lat 58° 45′ N., long 141° 10′ W. at locations shown on figure 62 and table 18 of Plafker and others (1979). A report concerning benthic foraminifers in S5–78–EG–43 and S5–78–EG–44 is provided by Rau (1979).

One sample (45C) from dredge S5–78–EG–45, water depth 2,600–3,000 m, was examined for coccoliths. Sample 45C contains abundant, diverse coccoliths of the lower Eocene *Discoaster lodoensis* Zone of Bukry (1973) (approximately 50 Ma). Biostratigraphic assignment of the assemblage is facilitated by the northernmost Pacific basin occurrence of the zonal guide species *Coccolithus crassus* Bramlette and Sullivan. *Discoaster*, *Sphenolithus*, *Braarudosphaera*, and *Micrantholithus* are common, but *Chiasmolithus* are sparse in sample 45C. The abundance of *Discoaster* and *Sphenolithus* with sparse *Chiasmolithus* indicates warm surface water conditions, whereas the abundance of *Braarudosphaera* and *Micrantholithus* indicates relatively shallow conditions. This sample was not examined for planktic foraminifers.

Two samples (43E and 43F) from dredge S5–78–EG–43, water depth 1,950–2,640 m, were examined for coccoliths, and one sample (letter designation unknown) was examined for planktic foraminifers. Samples 43E and 43F contain abundant, diverse warm water *Discoaster lodoensis* Zone assemblages similar to those of sample 45C; however, these samples lack *Braarudosphaera* and *Micrantholithus* and represent a more normal marine assemblage. *Discoaster barbadiensis* Tan, *D. lodoensis* Bramlette and Riedel, and *Discoasteroides kuepperi* (Stradner) are common in samples from both dredges.

Planktic foraminifers in sample 43 include: *Morozovella* sp. aff. *M. aragonensis* (Nuttall), *M. broadermanni* (Cushman and Bermudez) s.l., *Acarinina primitiva* (Finlay), and *A. nitida* (Martin). The common, but poorly preserved, planktic foraminifers indicate assignment of sample 43 to lower Eocene Zone P 7 or P 8 of Berggren (1972).

Three samples (44D, 44E, and 44F) from dredge S5–78–EG–44, water depth 1,270–1,450 m, were examined for coccoliths, and one sample (letter designation unknown) was examined for planktic foraminifers. The most age diagnostic coccolith assemblage, which also contains common *Braarudosphaera* fragments, was found in sample 44E. The occurrence of *Chiasmolithus* sp. cf. *C. solitus* (Bramlette and Sullivan), *Discoaster* sp. cf. *D. saipanensis* Bramlette and Riedel, and small *Reticulofenestra* sp. cf. *R. reticulata* (Gartner and Smith) and the lack of *Dictyococcites bisectus* (Hay, Mohler, and Wade) and *Reticulofenestra umbilica* (Levin) indicates a late middle Eocene age. A more diverse, better preserved coccolith assemblage containing common *Braarudosphaera* occurs in sample 44F, but the assemblage lacks taxa allowing specific zonation and could be part of the middle Eocene *Discoaster saipanensis* Subzone or upper Eocene *Chiasmolithus oamaruensis* Subzone (Bukry, 1975) on the basis of *Dictyococcites bisectus* (Hay, Mohler, and Wade), *Lanternithus minutus* Stradner, small *Reticulofenestra reticulata* (Gartner and Smith), and *Reticulofenestra umbilica* (Levin), without *Isthmolithus recurvus* Deflandre.

Sparse, poorly preserved planktic foraminifers from sample 44 include: *Pseudohastigerina micra* (Cole), *Subbotina linaperta* (Finlay), *Globorotaloides wilsoni* (Cole), *Globigerina minima* Jenkins, and *Clavigerinella* sp. (one specimen). The planktic foraminifer assemblage suggests assignment to the middle Eocene, most likely Zones P 12 to P 14 (Blow, 1969), and is compatible with the determination based on coccoliths for sample 44E.

Rau (1979) assigns a sample from dredge 44 (letter designation unknown) to the upper Eocene because of the occurrence of Narizian benthic foraminifers. The conflict between subseries assignments derived from planktic and benthic microfossils for dredge 44 may or may not be real. Recent work has shown that the Narizian Stage of the Pacific Coast correlates in large part with the middle Eocene of international usage (Bukry and others, 1977; Poore and Brabb, 1977; Poore, 1979). Thus, the Narizian benthic foraminifers recorded by Rau could be middle Eocene. Alternatively, coccoliths from sample 44F could be upper Eocene, and we cannot rule out the possibility that middle and upper Eocene rocks of similar lithology were sampled by dredge 44.

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Geologic implications of 1978 outcrop sample data from the continental slope in the eastern Gulf of Alaska

By George Plafker, Paul R. Carlson, Warren L. Coonrad, Susan J. Hunt, and Paula Quinterno

Between June 29 and July 10, 1978, the R/V *Sea Sounder* continued the program, begun in 1977 (Plafker, Winkler, and others, 1978), of sampling bedrock outcrops along the continental slope in the eastern Gulf of Alaska. Dredging was concentrated between the east end of the Aleutian Trench and Cross Sound (fig. 62), except for one cast made off Chichagof Island near Chatham Strait (not shown on fig. 62). The samples were taken to provide geologic control on the seaward margin of the Gulf of Alaska Tertiary Province, a major sedimentary basin that has long been of interest for petroleum exploration (Plafker, Bruns, and others, 1978), and to further understanding of the evolution of this active plate margin (Plafker, Hudson, and others, 1978). Part of this basin on the outer continental shelf, between Kayak Island and Icy Bay, was leased in April 1976, and 10 dry, deep exploratory wells were drilled for petroleum from 1976 to early 1978. A second lease sale (No. 55) has since been scheduled for mid-1980 in the segment of the continental shelf lying between Icy Bay and Alsek River (fig. 62).

Of 29 dredge casts attempted, 17 sampled bedrock, three sampled possible bedrock, and nine were empty or recovered only glacial erratics. The samples are from water depths ranging from 4,450 to 340 m. Locations for the bedrock samples are shown in figure 62, and selected preliminary sample data are summarized in table 18. In addition to the dredge casts, 16 gravity cores were attempted; only one penetrated the surficial mud and sampled the indurated sediment below.

The 1978 sample data, together with that collected in 1977, suggest the following tentative interpretation of the geology of the continental slope adjacent to the area of Lease Sale No. 55:

1) An Eocene and Oligocene sedimentary sequence, including interbedded argillaceous rocks, sandstone, boulder conglomerate, and mafic tuff, underlies much of the segment of continental slope, and rocks of comparable age may occur as far westward as the area off Middleton Island. The abundance of coarse conglomerate and carbonaceous material suggests that part of the sequence is a proximal facies.

2) The oldest Tertiary rocks dredged contain unusually well preserved and diverse assemblages of foraminifers and a diagnostic coccolith flora that indicate a late early Eocene age and deposition in relatively shallow (100–1,000 m) water depths; middle to upper Eocene rocks, in contrast, contain fossils more representative of open ocean conditions (Rau, 1979; David Bukry, written commun., July 21, 1978). The paleoenvironmental data suggest that these rocks were originally deposited in a subsiding shelf basin.

3) The Eocene sequence includes argillaceous rocks with favorable hydrocarbon source rock characteristics (Plafker and Claypool, 1979). Seven of the dredged samples contain argillaceous rocks with more than 1 percent and as much as 1.64 percent organic carbon. Some of the rocks have undergone a thermal history that has resulted in generation of hydrocarbons. In order to attain the degree of thermal maturity indicated, the rocks now exposed on the lower part of the continental slope were probably buried to depths of 3,000 m or more at some time during their history.

4) Microscopic examination of the recovered sandstone shows generally poor reservoir qualities; the sandstone ranges from poorly to moderately well sorted, contains abundant unstable rock fragments, is carbonaceous, has pervasive siliceous or calcareous cement, and commonly has low to moderate porosity. Exceptions are a friable medium-grained sandstone in dredge

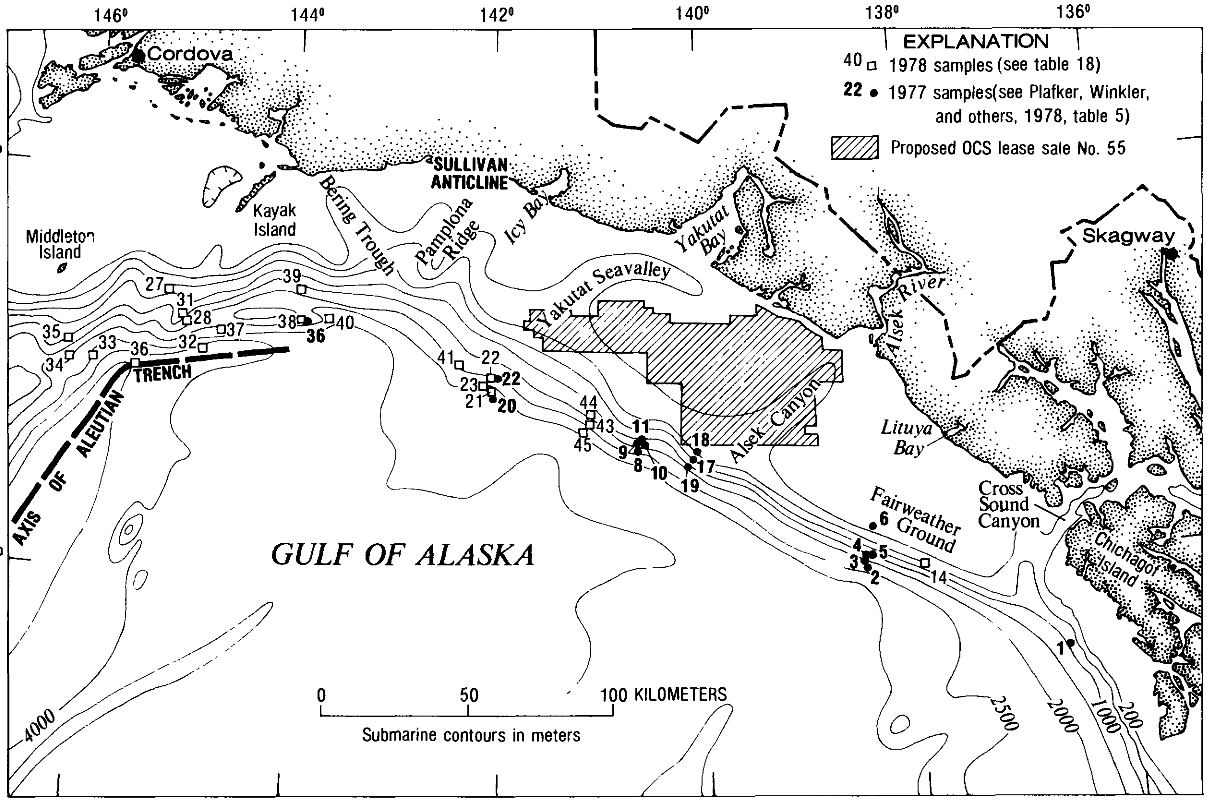

FIGURE 62.—Locations of bedrock outcrop samples from eastern Gulf of Alaska continental slope.

sample S5–78–EG–44 (sample 44 on fig. 62) with 31 percent porosity and 26 millidarcies (md) permeability, and one sandstone collected in the same area during 1977 with 24 percent porosity and 36 md permeability (S2–77–EG–10, sample 10 on fig. 62).

5) Analysis of multichannel seismic reflection data by T. R. Bruns (Plafker, Bruns, and others, 1978) indicates that the shelf edge is a structural high underlain by Eocene and Oligocene strata that form a wedge dipping and thinning toward the coast. The Paleogene section laps up on, or abuts against, a pre-Tertiary structural high that underlies part of the Fairweather Ground.

6) The present structural and topographic occurrence of the Paleogene sequence, together with the burial requirements to achieve thermal maturity, requires a complex evolutionary history for the continental slope. A possible scenario is: a) initial deposition and burial of the Paleogene rocks to depths of 3 km or more to achieve maturation of the sequence; b) uplift and erosion of at least 3 km of section to expose the mature rocks at the surface; c) removal of any distal equivalents of the Paleogene sequence that may have been present. Removal of the distal rocks may have resulted from strike-slip faulting and (or) subduction along the continental margin and may have been contemporaneous with (b); and d) subsidence of the Paleogene sequence to its present depths of 2–4 km below sea level along the continental slope.

Dredging west of Icy Bay has shown that Paleogene rocks are present along the base of the continental slope and along the inner margin of the Aleutian Trench, including the area where compacted Pleistocene hemipelagic siltstone (S2–77–EG–36) was collected in 1977 from water depths between 4,000 and 3,000 m (Plafker, Winkler, and others, 1978). The data preclude the possibility that any significant volume of deep-sea sediment has been accreted to this segment of the continental margin as a consequence of late Cenozoic crustal plate convergence. Instead, the oceanic crust and overlying thick sediments of the Pacific plate in the easternmost part of the Aleutian Trench have apparently been subducted beneath the North American plate without any appreciable

TABLE 18.—*Preliminary data on lithology, age, and location of outcrop samples recovered in 1978 dredge hauls*

Locality No.[1]	Lithology	Age or probable age	Water depth[2] (m)	Latitude[2] (N.)	Longitude[2] (W.)
14	Hard sheared sandstone; soft waxy diatomaceous siltstone	Late Miocene and Cretaceous	510	57°54.31'	138°02.45'
			340	57°54.57'	138°01.23'
21	Sheared carbonaceous quartzofeldspathic pebbly sandstone and minor brown carbonaceous micaceous siltstone	Eocene	2600	58°55.83'	142°06.57'
			2610	58°52.31'	142°03.39'
22	Hard quartzofeldspathic sandstone; hard black carbonaceous siltstone; brown waxy organic-rich moderately well indurated shale; cobble conglomerate	Eocene and older	2470	59°00.44'	142°08.55'
			2430	58°57.63'	142°09.39'
23	One chunk of arkosic sandstone (possibly erratic?)	--	2890	58°55.96'	142°10.78'
			4010	58°54.66'	142°14.41'
27	Pebbly sandy mudstone	Late Cenozoic and Paleogene	990	59°26.74'	145°14.43'
			785	59°26.58'	145°23.59'
28	Soft to moderately hard pebbly sandy mudstone	Late Cenozoic and Paleogene	2630	59°14.52'	145°03.68'
			2060	59°15.77'	145°05.31'
31	Hard pebbly sandy mudstone; soft sandy foraminiferal mudstone; hard calcareous siltstone; hard silty pyritic limestone	Late Cenozoic and Paleogene	3250	59°15.37'	145°00.12'
			2525	59°16.37'	145°02.32'
32	Brown calcareous sandy siltstone; hard gray quartzofeldspathic sandstone; "cannonball" calcareous concretions	Oligocene or Eocene	3430	59°08.29'	144°53.66'
			3450	59°08.29'	144°53.08'
33	A few chunks of soft pebbly sandy mudstone (possibly erratic?)	Late Cenozoic	4450	58°59.65'	145°55.76'
			4220	59°03.28'	145°59.52'
34	One cobble-size chunk of soft siltstone	Late Cenozoic	3870	59°04.49'	145°58.47'
			3250	59°08.52'	146°01.61'
35	Four cobble-size chunks of soft pebbly sandy mudstone and moderately hard glauconitic siltstone	Late Cenozoic and late Eocene	3350	59°05.75'	146°02.52'
			2650	59°07.64'	146°04.96'
36	Soft siltstone and hard calcareous siltstone	Late Cenozoic	3330	59°07.53'	145°43.23'
			2775	59°09.72'	145°43.11'
37	Soft sandy mudstone	Late Cenozoic and Paleogene	4090	59°11.93'	144°32.50'
			2850	59°13.26'	144°34.52'
38	Moderately hard siltstone and very soft sandy mudstone	Late Cenozoic and Eocene	4060	59°13.04'	144°28.96'
			3150	59°14.64'	144°28.22'
39	One chunk of soft sandy mudstone (possibly erratic?)	Late Cenozoic	2800	59°14.93'	144°30.59'
			2690	59°15.25'	144°31.95'

TABLE 18.—*Preliminary data on lithology, age, and location of outcrop samples recovered in 1978 dredge hauls*—Continued

Locality No.[1]	Lithology	Age or probable age	Water depth (m)	Latitude[2] (N.)	Longitude[2] (W.)
40	Soft to moderately hard radiolarian-bearing siltstone	Late Cenozoic	3680 2875	59°19.59' 59°21.88'	143°43.81' 143°43.48'
41	Hard sandstone and pebbly siltstone matrix, cobble-boulder conglomerate; one chunk of soft pebbly siltstone	Late Cenozoic and Eocene	3110 2700	59°02.94' 59°05.02'	142°26.51' 142°24.17'
43	Hard calcareous nannoplankton-rich siltstone; moderately hard slightly calcareous sheared siltstone; black palagonitized basaltic tuff	Early Eocene	2640 1915	58°45.60' 58°47.50'	141°12.64' 141°10.48'
44	Sheared hard clean foraminiferal and carbonaceous sandstone and soft highly fossiliferous organic-rich shale	Middle Eocene	1415 1270	58°45.90' 58°46.84'	141°08.49' 141°07.45'
45	Five cobble-size clasts, possibly from conglomerate; devitrified mafic tuff or volcaniclastic sandstone; soft waxy siltstone	Early Eocene	2955 2625	58°42.40' 58°43.83'	141°07.18' 141°03.58'

[1]Prefix S5-78-EG deleted from dredge locality numbers.
[2]Depth and coordinates are given for start and finish of dredge casts.

offscrapings, or accretionary wedge, of late Cenozoic age.

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