GEOLOGY OF THE
WESTERN ROMANZOF MOUNTAINS,
BROOKS RANGE, NORTHEASTERN ALASKA

FRONTISPIECE.—Oblique view of Romanzof Mountains along Okpilak River valley, looking west. In a spectacularly scenic area, mountains composed of granite rise to altitudes of 9,000 feet. Features of Pleistocene and Holocene glaciation abound. Photograph by U.S. Navy.

Geology of the Western Romanzof Mountains, Brooks Range, Northeastern Alaska

By EDWARD G. SABLE

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A comprehensive study of plutonic, sedimentary, and metamorphic rocks in an eastern Brooks Range area

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ENGLISH-METRIC EQUIVALENTS

English unit		Metric equivalent
Length		
inch (in)	=	25.4 millimetres (mm)
foot (ft)	=	30.48 centimetres (cm)
mile (mi)	=	1.609 kilometres (km)
Area		
square mile (mi^2)	=	2.590 square kilometres (km^2)

GEOLOGY OF THE WESTERN ROMANZOF MOUNTAINS, BROOKS RANGE, NORTHEASTERN ALASKA

By Edward G. Sable

ABSTRACT

The western Romanzof Mountains cover a remote 700-square-mile area in the Brooks Range, northeastern Alaska. The area is topographically rugged and geologically diverse; it contains a granitic pluton, low-grade metamorphic rocks, sedimentary rocks and mafic igneous rocks, as well as glacial features.

Rocks of sedimentary origin, from oldest to youngest are:

1. Neruokpuk Formation (Precambrian, Cambrian, and pre-Mississippian), more than 4,000 feet thick, consists of units of the greenschist facies, including quartzitic- and schistose-feldspathic to quartzose graywacke; phyllite, argillite, slate; minor chert; and limestone. The succession of units in parts of the area is uncertain. Correlations of these units with each other and with other units in the eastern Brooks Range are provisional.
2. Katakturuk Dolomite (Devonian or older), silicified carbonate rocks, mostly dolomite, with minor dark shale, carbonate conglomerate and breccia beds, pisolite and oolite beds. Probably more than 1,000 feet thick.
3. Kekiktuk Conglomerate and Kayak(?) Shale (Mississippian), a single map unit, 0(?)–420 feet thick, contains quartzite, interbedded dark shale, and some pebble- to boulder-conglomerate in the locally absent lower part (Kekiktuk), and, in its uppermost part, dark shale (Kayak(?)). The unit overlies the Neruokpuk and Katakturuk with angular unconformity, which may reflect either a pre-Kayak(?) or pre-Kekiktuk hiatus or both.
4. Lisburne Group, almost entirely carbonate rocks, is 600–800 feet thick in the northern part of the area and probably 1,200 feet thick in the southern part. Alapah Limestone (Upper Mississippian) of this group, as much as 560 feet thick, includes gray sandy, crystalline, and cherty limestones; minor dark shale; and, in the upper part, dark cherty carbonate rocks. Dark shaly and cherty carbonate rocks also constitute the lower part of the group in the southern part of the area. The lower contact is gradational with the Kayak(?) Shale. The Wahoo Limestone (Pennsylvanian) conformably overlies the Alapah, is 0–200+ feet thick, and is characterized by light-gray crinoidal limestones in its upper part.
5. Sadlerochit Formation, consisting of two members: the Echooka Member (Upper Permian) of iron-stained orthoquartzite and dark slate, 175–240 feet thick, which unconformably overlies the Wahoo and Alapah Limestones; and the Ivishak Member (Lower Triassic), consisting of a shale unit of dark shale, slate, and minor quartzite averaging 400 feet in thickness, and a quartzite unit, 700 feet thick, mostly orthoquartzite with minor shale and conglomerate. The basal clastics were probably shed from the north.
6. Shublik Formation (Middle and Upper Triassic), 600–700 feet thick, the thin phosphatic sandstone member is overlain by dark phosphatic limestones and limy shales of the limestone member.
7. Kingak Shale (Lower, Middle, and Upper Jurassic), probably more than 1,000 feet thick. The siltstone member, which is made up of resistant sandstone and siltstone 75–150 feet thick, is overlain by an undetermined thickness of black shale. The basal part contrasts sharply with the underlying Shublik, indicating possible disconformity.
8. Ignek(?) Formation (Lower and Upper Cretaceous), represented in the foothills where lithic graywacke, shale, and coaly shale constitute the few exposures examined.
9. Glacial and glaciofluvial materials of five advances recognized on the basis of morphology and position, which are tentatively correlated with five glaciations 15 miles west of the mapped area.
10. Recent alluvial and colluvial deposits, including fans which appear to represent at least three stages of encroachment.

Granitic rocks, exposed in the Okpilak batholith and Jago stock, are light-gray quartz monzonite to granite, with quartz, perthitic microcline, albite-oligoclase, and partly chloritized biotite. Limited modal and chemical data indicate calc-alkali biotite- to alkali biotite-granite compositions, relatively little variation in major oxides, but excessive quartz in some samples. Three textural facies are: (1) porphyritic (marginal), with abundant large microcline megacrysts; (2) variable (middle to marginal), which exhibits textural and mineralogical banding; and (3) coarse (inner to marginal), which is gneissoid to equigranular. Facies relationships appear to be mostly gradational but may be locally intrusive. Some xenoliths of schistose metasedimentary rock occur in the granite. Aplite dikes, inclusions, tourmaline veins and replacements, and chlorite and quartz veins are locally common, as are quartz monzonite and mafic igneous dikes. Contacts with the Neruokpuk Formation are mostly abrupt, concordant to crosscutting, and locally adjoin tactite and hornfels of the albite-epidote-hornfels and horblende-hornfels facies. Contacts with Kekiktuk Conglomerate appear to be gradational through a schistose zone. Primary structural elements in the granite include textural and mineralogical banding and, in general, feldspar foliation; biotite foliation, gneissic and schistose foliation, and schistose zones are considered secondary. Lead/alpha ages of zircons are Paleozoic (Devonian?); K-Ar age determinations indicate that the biotite is Cretaceous, possibly indicating updating of a Paleozoic granite by a Mesozoic metamorphic episode. Field age relationships are inconclusive but suggest Devonian granite emplacement. The pluton is interpreted to be essentially the product of melt crystallization, synorogenically emplaced by forceful injection with minor stoping, and may include marginally granitized rock.

Mafic igneous rocks of altered basaltic composition (greenstones) consist of dikes younger than granitic and Neruokpuk Formation rocks, and volcanics. They may be late Paleozoic or Mesozoic in age.

Structural grain strikes east-northeast; south-dipping elements are common. Structural features include the major positive nature of the area (first order), relatively broad folds (second order), and small tight folds within the broad folds (third order). Related south-dipping cleavage, schistosity, and biotite foliation in granite in the northern part of the area are cut by prominent sets of transverse joints and faults. Other features are longitudinal normal and reverse faults, overthrust faults, and sheared zones in granite with possible attendant retrograde metamorphism.

Although Mesozoic and Tertiary deformational features are dominant in northern Alaska, the Romanzof Mountains may have been part of a Late Devonian orogenic belt related to the Innuitan orogenic belt of the Canadian Archipelago.

The mineral potential of the area is largely unknown. Minor amounts of metallic sulfides and oxides are present in granite and contact-zone rocks. Analyses of stream silt samples suggest the possibility of tin and beryllium potential. The Shublik Formation contains rock phosphate.

INTRODUCTION

The Romanzof Mountains are geologically unique in northern Alaska; they contain the only known granitic plutonic rocks on the north side of the Brooks Range and exhibit considerable geological diversity. Geologic features include well-exposed granitic masses with a variety of contact relationships, low-grade metamorphic rocks, relatively unaltered sedimentary rocks, mafic intrusives and volcanics(?), and minor metallic mineralization. Bedrock units range in age from Precambrian to Cretaceous with all intervening geologic systems probably represented, and the units record evidence of at least two major unconformities. Pleistocene and Holocene glaciation are represented by striking piedmont and valley glacial features. Deformational features include high-angle normal and reverse faults, overthrusts, folds of several degrees of magnitude and complexity, and other features of dynamic and low-grade regional metamorphism.

LOCATION, SIZE, AND ACCESSIBILITY OF AREA

The Romanzof Mountains lie within the Mount Michelson and Demarcation Point quadrangles, Alaska; the area discussed herein lies in the western part of the Romanzof Mountains, covers about 700 square miles, and is approximately bounded by the Jago and Hulahula Rivers and by lats 69°05′ and 69°30′ N. (fig. 1). Airline distances from this area to the Alaskan settlements of Barter Island, Bettles, and Barrow are 60, 130, and 320 miles respectively. No roads or established trails are present into or within the area, which lies entirely within the Arctic Wildlife Range; access is most easily accomplished by small float- or ski-equipped aircraft. Within the area, surface travel is best accomplished on foot; tracked vehicle travel would be extremely difficult or impossible in the mountains. Shallow draft boats might be used on the major rivers, particularly on the Hulahula River, the largest and deepest stream in the area. (Since this report was written, active petroleum exploration in northeastern Alaska has resulted in additional settlement and airfield locations northwest of this area.)

PREVIOUS INVESTIGATIONS

The Romanzof Mountains were named by Sir John Franklin (1828, p. 145–147), who saw their snow-clad peaks from the Arctic Coast. The name was later restricted to that part of the mountains between the Hulahula and Jago Rivers by Ernest deK. Leffingwell (1919, p. 50), who, while undertaking geologic and topographic investigations in northeastern Alaska, made two trips into the area. The information gathered on these trips, though of a reconnaissance nature, served to outline some of the major rock units and the gross structural character of the region. Leffingwell was a keen observer; he established the stratigraphic nomenclature for the northeastern Brooks Range, and many of his stratigraphic units are still valid.

In June 1948, a U.S. Geological Survey party, consisting of C. L. Whittington, E. G. Sable, and A. H. Lachenbruch, conducted a geologic reconnaissance which included areas along the Okpilak and Hulahula Rivers and along the front of the mountains between these rivers (Whittington and Sable, 1948). This work resulted in few refinements of Leffingwell's earlier observations.

NATURE AND SCOPE OF PRESENT INVESTIGATION

The purposes of field studies undertaken during the summers of 1957 and 1958 were to produce a fairly detailed geologic map of the area, to determine the age and relationships of the various rock units, to compare the sedimentary rock succession with those in other areas of northeastern Alaska, and to evaluate the structural features and possible economic mineral potential. Most of my efforts were devoted to studies of structure, physical stratigraphy, and the granitic rocks; observations of glacial features were incidental to bedrock studies. Although the results are considered to be semidetailed in nature, the amount of data exceeds that from most Alaskan areas.

Fieldwork was undertaken from June 10 to August 25, 1957, and from June 10 to September 2, 1958. I was assisted by George R. Kunkle in 1957 and by Ralph S. Bunnell in 1958. Transportation between the area and Barrow, the main base of operations, was by ski- and float-equipped aircraft. Base camps were established at Jago and Okpilak Lakes; other temporary camps were made by backpacking and airdropping of food and equipment. Additional observations in June and July of 1969 were made by me in conjunction with U.S. Geological Survey studies in the area.

During fieldwork, the geology was mapped directly on high-altitude trimetrogon, vertical, and low-oblique

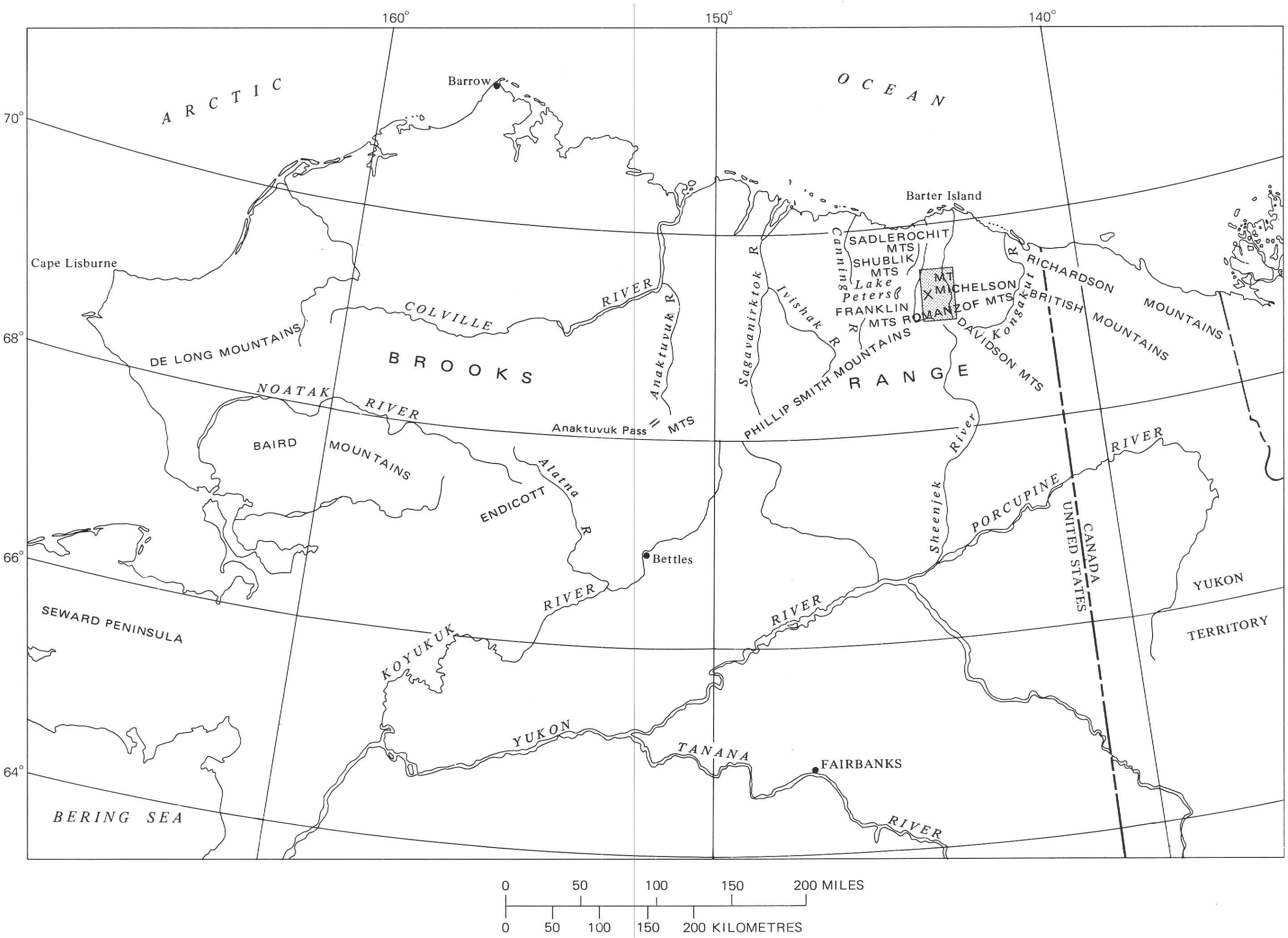


Figure 1.—Index map of northern Alaska showing location of report area (shaded).

transverse aerial photographs, and on low-altitude oblique photographs, flown by the U.S. Army, U.S. Navy, and a private contractor for the U.S. Geological Survey. The photographs were also used to extend mapping into those parts of the area not visited during fieldwork. Data were transferred from aerial photographs to unpublished 1:63,360 topographic maps with contour intervals of 100 and 200 feet, prepared by the U.S. Geologocal Survey.

The sedimentary rocks exposed in the northwestern part of the area between the Okpilak and Hulahula Rivers have been described by Bunnell (1959), and a preliminary description of most of the sedimentary and metamorphic rocks in the area as a whole was given by me (Sable, 1959). Glaciation along the Jago and Okpilak Rivers was studied by Kunkle (1958). Continued regional studies of Paleozoic stratigraphy in the eastern Brooks Range by the U.S. Geological Survey (Brosge and others, 1962; Dutro, 1970; Reiser, 1970; Dutro and others, 1972) have resulted in reevaluation of some previous interpretations of Sable (1959) and Bunnell (1959). A study of the nearby Lake Peters area (Reed, 1968) is also pertinent to geological interpretations in the Romanzof Mountains.

ACKNOWLEDGMENTS

Fieldwork in 1957–58 was supported financially by the Arctic Institute of North America under contractual arrangements with the Office of Naval Research and by the U.S. Geological Survey. It was supported logistically by the Arctic Research Laboratory staff at Barrow, under the supervision of Max C. Brewer. I gratefully acknowledge this support as well as the assistance of other scientific investigators in the area—Charles M. Keeler of the McCall Glacier International Geophysical Year Glaciological project; Dr. Jerry Brown, pedologist, Rutgers University; and Dr. John E. Cantlon, botanist, Michigan State University. Investigations by Bunnell (1959), Kunkle (1958), and Keeler (1959) are incorporated in this report, as well as the work west of the Hulahula River by Whittington and Sable (1948). Bruce L. Reed, U.S. Geological Survey, confirmed identifications of some minerals by X-ray diffraction and petrographic methods.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

The Romanzof Mountains, the highest and most rugged mountain mass in the northern part of the Brooks Range, reach altitudes of more than 9,000 feet, with relief of as much as 7,000 feet. They are nevertheless a relatively small group of mountains compared with other components of the Brooks Range, such as the Endicott, Baird, De Long, and Phillip Smith Mountains. The Romanzof Mountains rise rather abruptly from low hills on the north, and their northern parts consist of high, mostly rubble-covered uplands with terracelike erosional surfaces at several altitudes, linear ridges, and irregularly shaped mountains. These rise gradually toward the central part of the Romanzof Mountains, where massive, precipitous mountains with jagged peaks and ridges are the dominant topographic features (frontispiece). Many valley glaciers as long as 6 miles head in the higher parts of the area, where several small icecaps occur, including one on Mount Michelson, one of the highest peaks in the Brooks Range.

Three major north-flowing rivers, the Jago, Okpilak, and Hulahula, drain the area. Their valleys have been heavily glaciated and, except in their headwaters, are wide and U-shaped. Gradients are steep, and, at present, downcutting seems to be the major erosional process of these rivers, although braided areas locally give the impression of extensive lateral cutting. Tributary streams such as Okpirourak, Leffingwell, McCall, Old Man (Angayukasrakuvik of some reports), and Esetuk Creeks are deeply incised within the mountains. Valley profiles of the tributaries are generally V-shaped and steep sided.

Overgraded and unstable slopes are common in the area; as a result, numerous evidences of soil creep, soil flow, and other surface material instability are present. Rockfalls and small avalanches are common occurrences in the higher mountains. Patterned-ground features are abundant in the foothills north of the Romanzof Mountains, and the entire area is probably underlain by permafrost. Mechanical disintegration is currently the prime weathering agent.

STRATIGRAPHY

Sedimentary and metasedimentary rocks in and adjoining the western Romanzof Mountains compose more than 8,000 feet of strata which are largely marine and which range in age from Precambrian to Cretaceous (table 1). Rocks of Precambrian to pre-Mississippian age appear to reflect geosynclinal depositional environments. Younger Paleozoic and Triassic sequences have shelf characteristics; Jurassic rocks suggest deeper basin conditions. Cretaceous rocks were deposited in nearshore to marginal marine environments.

TERMINOLOGY AND METHODS

The terms "clastic" and "detrital" are used herein for terrigenously derived arenaceous and argillaceous rocks as distinguished from rocks of dominantly carbonate composition regardless of their mode of deposition. Descriptions of both clastic and carbonate rock types are based on the Wentworth (1922) scale, and the adjectives "clay" and "silty" refer to grain size. The term "shale" generally follows the usage of Pettijohn (1957, p. 341), as does the classification of sandstones examined in thin section (Pettijohn, 1957, p. 291). Descriptions of stratification and splitting properties generally follow those of McKee and Weir (1953, p. 383). The color designations correspond insofar as possible to the color names of the National Research Council "Rock Color Chart" (Goddard and others, 1948). Delineation of rock-stratigraphic units and nomenclatural terminology conform with the "Code of Stratigraphic Nomenclature" (Am. Comm. Strat. Nomenclature, 1970).

Section thicknesses of sedimentary rocks were obtained by pace-and-compass traverse, altimeter traverse, direct measurement, and estimation. The resulting thicknesses are approximate; the nature of the terrain and the necessity of covering a large area in a limited time were factors which precluded a higher degree of measurement accuracy and descriptive detail.

Laboratory studies included examination of many specimens under the binocular microscope and examination of 40 standard thin sections of the sedimentary rocks.

PRECAMBRIAN AND LOWER PART OF PALEOZOIC ERAS

Rocks of pre-Mississippian age in the western Romanzof Mountains are placed in the Neruokpuk Formation of Precambrian, Cambrian, and pre-Mississippian age, made up largely of clastic rocks, and the Katakturuk Dolomite of Devonian or older age, which consists largely of carbonate rocks.

NERUOKPUK FORMATION

NAME AND DEFINITION

The Neruokpuk Schist as first used by Leffingwell (1919, p. 103–105) denoted chiefly quartzite schists in an eastward-trending belt "from a point west of the Canning to the Hulahula and probably to the Okpilak and beyond". Leffingwell included no carbonate rocks in the Neruokpuk. Whittington and Sable (1948, p. 3–4) also restricted the Neruokpuk to noncarbonate rocks believed to be pre-Mississippian in age and included units of phyllite and argillite, but did not attempt to subdivide the formation.

In the preliminary summary of my 1957–58 investigations (Sable, 1959, p. 17–26), I described an apparently un-

TABLE 1.—*Summary of sedimentary rocks and surficial deposits, western Romanzof Mountains, northeastern Alaska*

Age	Name of unit		Approximate thickness (feet)		Generalized description
			Northern part of area	Southern part of area	
Holocene and Pleistocene	Unnamed		0–200(?)		Glaciofluvial, alluvial, and colluvial silt, sand, and gravel; mostly granitic consitutents. Ice and ice-contact deposits; till, coarse morainal deposits.
Late and Early Cretaceous	Ignek(?) Formation		Unknown		Dark-gray shale, sandstone, siltstone, coaly beds.
Late, Middle, and Early Jurassic	Kingak Shale		1,000+		Predominantly dark-gray clay and silty shale. Basal silty quartzite with minor conglomerate beds.
Late and Middle Triassic	Shublik Formation		600–700		Black phosphatic limestone and limy shale, Basal phosphatic sandstone.
Early Triassic	Sadlerochit Formation	Ivishak Member	400+–500(?)		Quartzite unit, medium-gray massive quartzite with interbedded slate, limy sandstone, and minor conglomerate.
	Sadlerochit Formation	Ivishak Member	400±		Shale unit, predominantly dark-gray slate and shale, partly laminated. Minor thin quartzite interbeds.
Late Permian	Sadlerochit Formation	Echooka Member	200±		Ferruginous quartzite with minor conglomerate lenses, interbedded with slate and ferruginous sandstone.
Middle and Early Pennsylvanian	Lisburne Group	Wahoo Limestone	0–200+	(?)	Carbonate rocks. Fine-grained to coarse fossil fragmental limestone; dolomite; lower part of the Alapah is silty and sandy limestone with minor shale beds in northern part of area; lower part of the Alapah in southern part of area, black cherty unit, is dark limestone, shale, and chert.
Late Mississippian	Lisburne Group	Alapah Limestone	200(?)–560	1,200+(?)	
Mississippian	Kayak(?) Shale and Kekiktuk Conglomerate		0(?)–420		Light- to dark-gray silt- to granule-sized quartzite interbedded with and overlain by variable amounts of carbonaceous shale and slate. Local pebble to boulder conglomerate.
Devonian or older	Katakturuk Dolomite		1,000±		Siliceous carbonate rocks, mostly dolomite. Includes aphanitic, laminated, oolitic, and pisolitic varieties and sedimentary breccia.
Pre-Mississippian, Cambrian, and Precambrian	Neruokpuk Formation (several informal units)		4,000+		Gray and brown or green quartzitic and schistose graywacke with interbedded slate and lesser siliceous rocks (metachert). Dark limestone and shale, crystalline to sandy. Argillite, phyllite, slate.

faulted sequence of Neruokpuk rocks along the Jago River, and briefly discussed carbonate and clastic rocks west of the Okpilak River. Bunnell (1959, p. 10–24) discussed two members of the Neruokpuk north of the granitic rocks between the Okpilak and Hulahula Rivers; both he and I included carbonate units in the Neruokpuk.

Currently, the Neruokpuk comprises some units of a larger stratigraphic complex which is overlain unconformably by Mississippian rocks. At least one and possibly several major unconformities occur within the Neruokpuk.

Subdivisions of the Neruokpuk in recent years include those by Brosgé, Dutro, Mangus, and Reiser (1962), Sable (1965), Gryc, Dutro, Brosgé, Tailleur, and Churkin (1967), Reed (1968), Reiser and Tailleur (1969), and Reiser (1970). A reinterpretation of the Neruokpuk by Dutro, Brosge, and Reiser (1972) indicates that at least six different sequences with different members occur in separate outcrop belts. The stratigraphic succession in three of the sequences has been established; in the other three, part of which includes the northern part of the Romanzof Mountains, different members have been defined but their relationships and ages are uncertain.

Several thick rock units, including carbonate rocks, are herein ascribed to the Neruokpuk Formation in the western Romanzof Mountains. Some units can be provisionally correlated with units recognized by other workers; the status of others is uncertain. The Neruokpuk Formation is a nomenclatural unit of diverse lithologies. The paucity of fossils, the character and thicknesses of lithic units which indicate the possibility of rapid and as yet unpredictable facies changes, unconformities within and above the formation, and structural complexity and metamorphism make the Neruokpuk the most enigmatic unit in the eastern Brooks Range.

DISTRIBUTION AND OUTCROP

Neruokpuk rocks are exposed almost continuously around the periphery of the granitic pluton which dominates the area (plate 1) except along its northern limits of exposure; they also crop out north of the pluton along part of Old Man Creek. Within the mapped area, Neruokpuk exposures make up less than 200 square miles, but much more extensive belts of exposure continue many miles southward and westward, and eastward to beyond the Canadian border (Brosgé and others, 1962, p. 2175, 2182).

In the Romanzof Mountains, the most resistant Neruokpuk rock types are the quartzitic and schistose units which comprise most of the high mountains adjoining the granite along the Jago River and in the Okpilak River headwaters. The carbonate and fine-grained metasedimentary rocks commonly weather to rubble-covered hills and swales. Thick well-exposed sections in the area occur in the north-facing mountainsides along the west side of the Jago River south of Hubley Creek, and in the headwaters of the Okpilak River.

In many places, rocks of the Neruokpuk Formation are highly deformed, with well-developed cleavage and schistosity which mask original bedding features. When viewed from a distance, entire mountainsides, particularly those south of the granite, appear to be made up of enormously thick sections of south-dipping bedrock. Closer examination, however, reveals isoclinal folds and zones of shear which parallel foliation in these rocks and which indicate much structural duplication in the unit.

LITHOLOGIC CHARACTER, THICKNESS, AND CORRELATION

Metasedimentary rocks of the Neruokpuk Formation consist of quartzites and schistose quartzites, phyllites, argillites, slates, limestones, and minor cherty rocks. The total thickness of the formation is not known, but it exceeds 4,000 feet in this area.

As the result of the 1969 fieldwork, some units previously included in the Neruokpuk Formation in parts of the area (Sable, 1965) have been reassigned. Sooty shale, graphitic slate, phyllite, limestone, and quartzite in the headwaters of the Okpilak and Jago Rivers which were previously mapped in the Neruokpuk are now known to be Lisburne, Kayak(?), and Kekiktuk strata, as are some rocks north of Esetuk Glacier (pl. 1). The silicified carbonate unit (Sable, 1965, p. 25–29) along the Hulahula River and Old Man Creek is withdrawn from the Neruokpuk Formation and is assigned to the Katakturuk Dolomite.

Three areas in the western Romanzof Mountains display somewhat different sequences, which at present cannot be correlated with certainty. These are the Jago River and west into the headwaters of the Okpilak River, Old Man Creek, and the vicinity of Esetuk Glacier.

JAGO RIVER AND OKPILAK RIVER HEADWATERS

The Neruokpuk rocks in the Jago River area, including the well-exposed reference section ¼ mile south of Hubley Creek have been described earlier (Sable, 1959, p. 19–24). Rock units in this reference section, with thicknesses partly revised, are described briefly in table 2 and in more detail in measured sections 1 and 2 of the present report.

Below this section calc-silicate and schistose rocks reflect alteration by emplacement of adjoining granite. Units in the section seem structurally conformable and relatively uncomplicated, but they may not be in normal stratigraphic order. Bedding-plane or overthrust faults may be present between or within units. As discussed below, the stratigraphic sequence does not correspond exactly to others in the eastern Brooks Range.

Units in the reference section can be traced westward about 3 miles where they appear to pinch out or to be truncated by granite. East of the Jago River and 2–3 miles north, similar units are correlated with units in the reference section on the basis of lithic and sequential similarity. Unit 3, the brown-weathering quartzite, appears to be the key unit that ties the two belts of exposures. East of the Jago River, unit 3 is underlain and overlain by units that are lithologically similar to those in the reference section. Here, unit 3 is probably more than 800 feet thick; on aerial photographs it appears to thicken eastward to a point 12 miles east of the Jago River where it strikes under Mississippian rocks. Westward, unit 3 appears to thin and pinch out before the sequence is truncated by granite.

In thin section the quartzites from units 3, 6, and 7 of the reference section are schistose and contain about 50–90 percent grains which are compressed, subround to angular, and poorly sorted and packed. Grains consist of quartz (70–95 percent), plagioclase (probably albite–oligoclase; 5–15 percent), perthitic microcline (5–10 percent), few rock fragments, and minor resistates which include zircon, staurolite(?), rutile(?), sphene, and ore minerals. Matrix material is microcrystalline quartz, sericite, chlorite, and, locally, iron oxides and biotite. Chlorite appears to have replaced biotite and may indicate retrograde metamorphism. Although the quartzites contain more quartz than do the granitic rocks of the area, the mineralogy is similar in both rocks. Granular microaggregates of matrix quartz in some sections also resemble the bimodal size distribution of some of the granitic rocks. The rocks can be classified as schistose quartzite, and most of them were originally feldspathic graywacke. Carbonate rock in the reference section (units 1–4) is fine-grained calcite marble with a few grains of corroded quartz, chert, and plagioclase. Carbonate grains are commonly elongate and subparallel; minor dark opaque material is probably organic.

Suggested lithologic correlations with Neruokpuk units described by Dutro, Brosgé, and Reiser (1972) are shown in figure 2. These correlations indicate that all units in the reference section are not in normal succession. Dark limestones of reference section units 1 and 2 seem almost identical to those in their limestone member.

TABLE 2.—*Generalized description of the reference section of Neruokpuk Formation South of Hubley Creek*

Map unit (pl. 1)	Unit	Approximate total thickness (feet)
Limy siltstone	8. Calcareous siltstone, slate, quartzite; weathers brown	3000?
Quartzite	7. Quartzite and schistose quartzite, to granule-sized grains, with chloritic and sericitic schist, slate, and minor limy sandstone. Green hues dominant	4000?
	6. Quartzite, to granule size, with minor siliceous shale or slate. Unit is predominantly gray and olive gray; weathers brown	700
	Fault?	
Phyllite, chert, and limestone	5. Argillite, phyllite, and siliceous shale or slate that are gray, grayish green, and grayish red, and chert that is light gray to dark gray	350
	4. Limestone, dark-gray; in part sandy	300
	Fault?	
Brown-weathering quartzite	3. Quartzite, gray, to granule size, with minor calcareous sandstone. Unit weathers brown and appears to pinch out westward	400
Limestone	2. Limestone, gray, and phyllite, gray to grayish-green, with quartzite, dark slate, and schist	700
	1. Limestone, black and gray with very minor slate, phyllite, siltstone, and quartzite; sandy limestone in upper part	1,000+

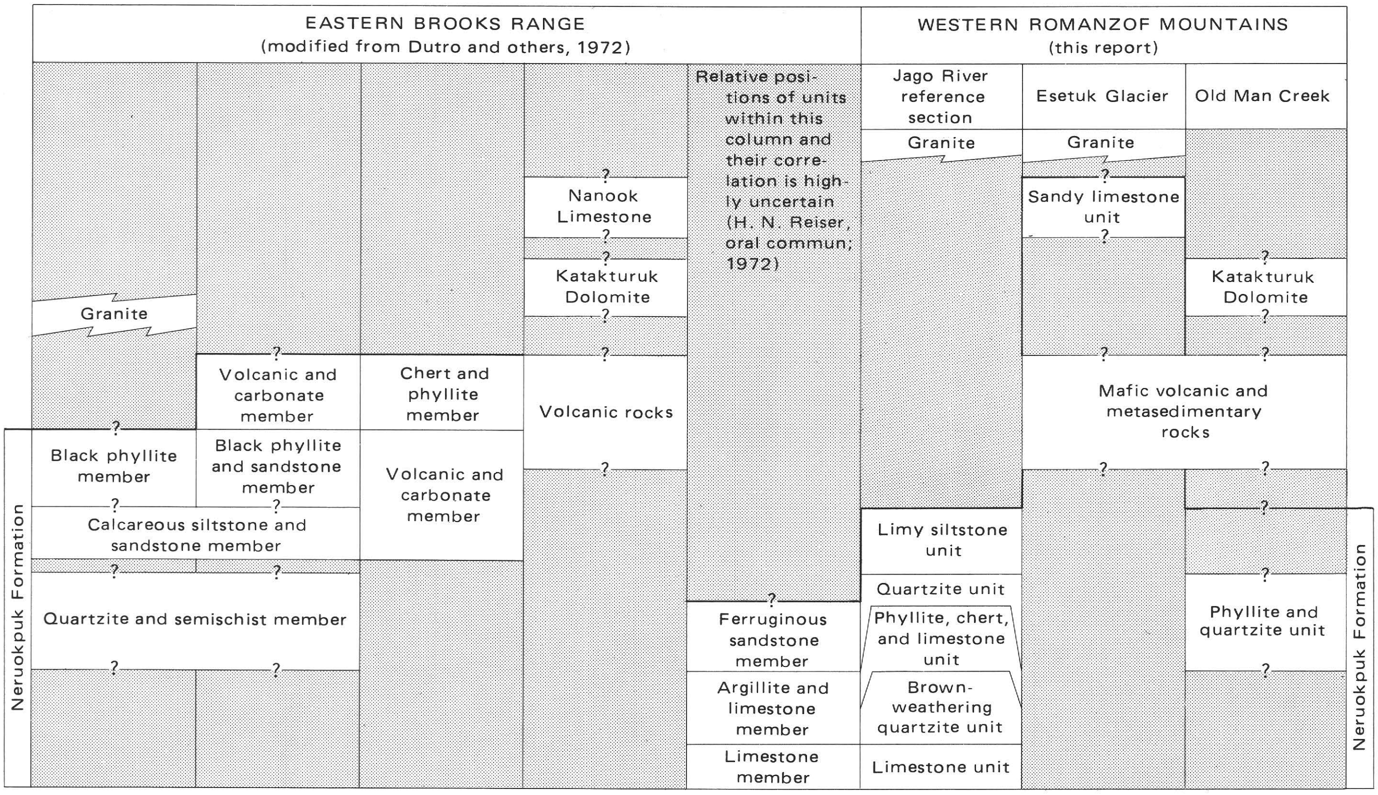


FIGURE 2.—Suggested correlations of pre-Mississippian rocks in the western Romanzof Mountains with those in the eastern Brooks Range. (Heavy lines denote limits of Neruokpuk Formation.)

Unit 3 appears to be anomalous, and may be a fault sliver of the quartzite member, but it is shown as a part of the succession on the geologic map. Units 4 and 5 may be their chert and phyllite member; the red and green rocks in unit 5 suggest this. Units 6 and 7 of the reference section contain lithologies like those of their quartzite-schist and semischist member, and unit 8 correlates well on a lithologic basis with their calcareous siltstone and sandstone member.

North of the reference section, rocks which immediately underlie the younger Kekiktuk Conglomerate are poorly exposed on the east and west sides of the Jago River 5 and 5½ miles south of Jago Lake, respectively. These consist of perhaps several hundred feet of reddish-gray and greenish-gray phyllite and argillite interbedded with lesser amounts of schistose quartzite. These rocks may be part of the argillite and limestone member of Dutro, Brosgé, and Reiser (1972).

Neruokpuk rocks exposed south and west of the reference section are largely quartzite, schistose quartzite, slate, phyllite, and lesser amounts of limy siltstone and sandstone; they strike southwest, subparallel to the margins of the granite, into the Okpilak River headwaters. Lithologic character and estimated thicknesses of the sequence adjoining the granite along Schwanda Glacier (C. M. Keeler, written commun., 1958; aerial photograph and 1969 field reconnaissance by Sable and H. N. Reiser) indicate 1,500(?) feet of light-gray banded quartzitic rock, probably hornfels, overlain by 200(?) feet of black slate with interbedded black chert, overlain by as much as 3,000 feet of the brownish-weathering limy siltstone unit. The quartzitic rock is correlated with the quartzite and semischist member, and the overlying rocks with the calcareous siltstone and sandstone member of Dutro, Brosgé, and Reiser (1972).

In the headwaters of the Okpilak River, gray and grayish-green chloritic quartzites and quartz-mica to quartz-chlorite schists with lesser amounts of slate, phyllite, and thin limy sandstones are tentatively correlated with units 6 and 7 of the Jago River reference section. Their thickness probably exceeds 2,000 feet; they overlie about 500 feet of phyllite and quartzite near the forks of the Okpilak and locally are intruded by granite.

OLD MAN CREEK

Bunnell (1959, p. 10–24) described two rock units that he placed in the Neruokpuk Formation: a quartzite member (phyllite and quartzite unit of the present report) more than 300 feet thick, and an overlying silicified limestone member (Katakturuk Dolomite of the present report), about 400 feet thick along Old Man Creek and perhaps as much as 800–1,000 feet along the Hulahula River.

The phyllite-quartzite unit is exposed in a small area along Old Man Creek near its junction with Slippery

Creek. The upper part is mostly gray slate, argillite, and phyllite. Light- to dark-gray quartzite is dominant in the lower one-half of the exposed sections. (See measured section 3.) It apparently underlies mafic igneous rocks; but relationships with these and with the overlying Katakturuk Dolomite are not known.

ESETUK GLACIER VICINITY

Reexamination of exposures in the Esetuk Glacier vicinity, in 1969, resulted in new interpretations regarding assignment of rock units. Some rocks that were previously placed in the Neruokpuk Formation (Sable, 1965, p. 23–25) are here reassigned to younger units, and the gross lithology and possible correlations of others are reevaluated. North of the Esetuk Glacier terminus, rocks previously correlated with the silicified carbonate unit of the Neruokpuk (present Katakturuk Dolomite) are reassigned to the Lisburne Group. The sandy limestone unit of the Neruokpuk (Sable, 1965), which strikes under Esetuk Glacier, is provisionally retained in that formation. This unit, at least 500 feet thick, contains gray, silty to sandy, yellow-brown-weathering platy limestone, black shaly to silty limestone, and orange-weathering limestone. Correlation of this unit with the Nanook limestone on figure 2 is highly speculative. Rocks previously referred to the phyllite-quartzite unit northeast of Esetuk Glacier (Sable, 1965) are a complex of mafic rocks, phyllites, and argillites similar to the mafic rocks and associated metasedimentary rocks along Old Man Creek and the Hulahula River; they are correlated with that unit. Rocks formerly referred to the phyllite-quartzite unit southwest of Esetuk Glacier, although provisionally retained in the Neruokpuk Formation, may also be a mafic igneous and metasedimentary complex; they consist of iron-stained, siliceous, slaty, and greenstonelike rocks which have been altered apparently during emplacement of the adjoining granite. Farther south, Neruokpuk rocks underlying younger units are predominantly gray and grayish-green quartzites and phyllites which are also similarly altered where they adjoin granitic rocks; they are correlated with the quartzite and semischist member of Dutro, Brosgé, and Reiser (1972).

AGE

No identifiable fossils were found in rocks of the Neruokpuk Formation in this area. Questionable fossil remains in the limestones of the lower part of the reference section along the Jago River and in the other carbonate rocks of small, deformed, calcite- or quartz-filled ellipsoids.

Payne (1952) considered the Neruokpuk Formation, as defined by Leffingwell, to be of possible Precambrian age. Brosge, Dutro, Mangus, and Reiser (1962) reported no fossils from the Neruokpuk, but they tentatively correlated its members, except for the quartzite-schist member, with units of Middle(?) and Late Devonian age exposed on the south side of the Brooks Range. There, the Skajit Limestone, with which some of the Neruokpuk carbonate rocks may be correlative, contains Middle(?) and Late Devonian fossils. They considered the quartzite-schist member of the Neruokpuk to be of Devonian or pre-Devonian (?) age. Reed (1968, p. 26) implied that the Neruokpuk Formation in the Lake Peters area may represent lower Paleozoic strata. Dutro (1970) suggested that the Neruokpuk may range in age from Precambrian to Devonian with part of it certainly being older than Ordovician. Fossils in the Neruokpuk Formation were found at other northeastern Brooks Range localities in 1970 and 1971. They include Middle(?) to possibly Early Devonian brachiopods, Late Ordovician graptolites, and Early and Late Cambrian trilobites (Dutro and others, 1971). The formal age designation of the Neruokpuk to include strata of Devonian age has not yet been published. Thus, inclusion of this age for Neruokpuk rocks is omitted here, except that the sandy limestone unit of Esetuk Glacier vicinity is provisionally placed in the Devonian System in figure 2.

KATAKTURUK DOLOMITE

Carbonate rocks and minor land-derived clastics underlie the Kayak(?) Shale and Kekiktuk Conglomerate and overlie Neruokpuk Formation and mafic rocks in steep mountainsides along Old Man Creek and the Hulahula River. They are correlated with the Katakturuk Dolomite (Dutro, 1970) of the Shublik and Sadlerochit Mountains, about 30 miles northwest of the Romanzof Mountains. These rocks were previously included in the Lisburne Limestone (Whittington and Sable, 1948) and in the Neruokpuk Formation by Bunnell (1959) and by Sable (1965).

Several sections illustrating the variable character of the Katakturuk Dolomite and its unconformable relationships with overlying rocks along Old Man Creek and the Hulahula River are shown in figure 3; one section is described in measured section 4. The lower one-quarter to one-half of the exposures is dominantly medium-to dark-gray, very fine to fine-grained, laminated to uniform carbonate rock which weathers to lighter gray, yellowish-gray, and orange hues, generally in massive, rough-surfaced outcrops. Some carbonate-rock breccia occurs in the lower part, and the upper 150–250 feet is characterized by these more exotic rock types, such as breccia in units as much as 80 feet thick, granule- to boulder-sized carbonate-rock conglomerate as much as 40 feet thick, lesser amounts of interbedded black shale, siltstone, and pisolitic to oolitic carbonate rock. Laminated and uniform beds of carbonate rock also occur as discrete units and within some of the brecciated units.

Breccia occurs in irregular beds and consists mostly of tabular siliceous limestone and dolomite fragments, commonly less than a few inches in either dimension but as much as 4 inches by 2 feet. Most fragments, commonly angular but also subround to round, are laminated carbonate rock embedded in very fine grained, in part silicified carbonate which makes up 20–60 percent of the rock. At least some breccia fragments appear to be derived from subjacent beds. Limestone conglomerate, of similar composition to the breccia, is poorly sorted and contains round to subround boulders of light-gray, partly silicified carbonate as much as 3 feet in diameter and subround to angular pebbles and granules of laminated to uniform carbonate cemented by about 50 percent very fine grained silicified carbonate matrix. Although many angular breccia fragments appear to have moved only short distances, and may therefore have originated by local solution collapse, their similarities to the conglomerate constituents as well as their association with rounded fragments in the breccias suggest a sedimentary origin.

Moderately well sorted pisolitic and oolitic carbonates 10–20 feet thick, where seen along Old Man Creek, appear to be confined to one horizon about in the middle of the Katakturuk Dolomite; they have also been reported along the Hulahula River (C. L. Whittington and E. G. Sable, unpub. data, 1960).

Most of the carbonate rocks effervesce only slightly with dilute HCl. In thin sections, they consist of very fine to fine-grained intergrowths of 25–80 percent anhedral dolomite grains with granoblastic texture, and microcrystalline quartz and calcite. Rounded carbonate grains in quartz matrix are also present, and ooliths are composed of intergrown calcite and quartz. All of these rocks appear to be of uniformly low porosity and permeability.

Terrigenously derived clastic rocks, particularly black shale, generally resemble those of the Kayak(?) Shale, and

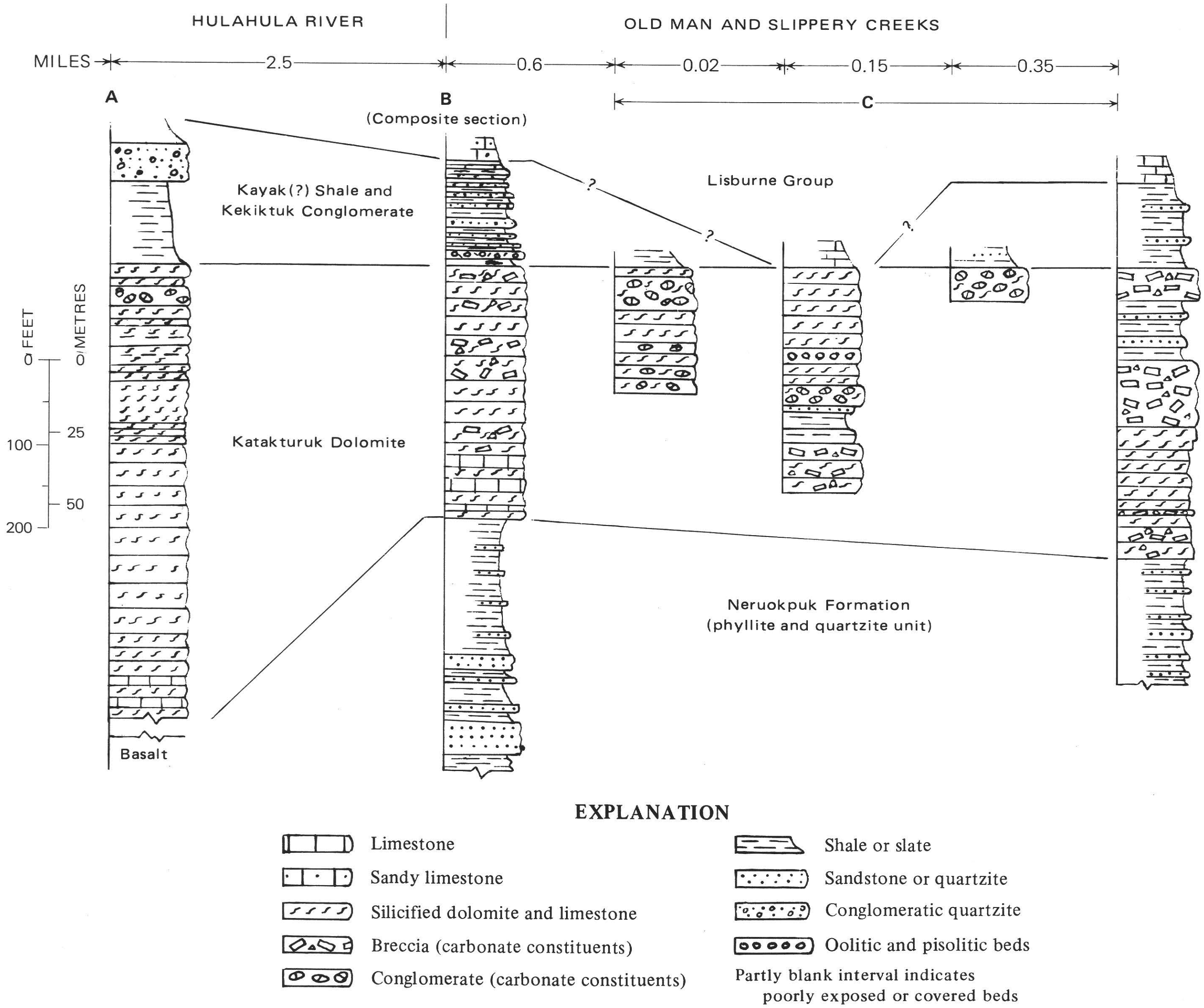


FIGURE 3.—Columnar sections showing Katakturuk Dolomite, Kekiktuk Conglomerate, and Kayak(?) Shale in northwestern part of Romanzof Mountains. See geologic map (pl. 1) for locations of sections.

are interbedded with carbonate rocks mostly in the upper 50–100 feet of the Katakturuk Dolomite sections. Locally the shales give the impression that the formation grades upward into the Kayak(?).

In many outcrops, rocks of the Katakturuk Dolomite are characterized by internal flowage, minute-to large-scale bedding dislocations, and tight folding, in part at least followed by recementation and recrystallization. Along the Hulahula River the strata overlie but also apparently interfinger with or are in part engulged in volcanic(?) mafic rocks (C. L. Whittington and E. G. Sable, unpub. data, 1960). The only recognized base of the formation in the area is along Old Man Creek where it rests on the phyllite and quartzite unit and mafic rocks. The total thickness of about 350–400 feet in Old Man Creek drainage is a composite of several partial sections. The thickness along the Hulahula River is estimated to be as much as 1,000 feet.

The Katakturuk Dolomite is overlain by the Kekiktuk Conglomerate, Kayak(?) Shale, and at some localities possibly by Lisburne Group. The precise delineation of this contact, which represents a major unconformity, is difficult in places where dark shales and siltstones are associated with rocks both above and below the boundary. In other places, the contact is sharp and easily recognized.

Correlation of the dolomitic rocks of this area with the Katakturuk Dolomite in the Shublik Mountains is based wholly on lithology. The lithologic correlation, however, is on fairly firm grounds because some distinctive lithologic features not seen in other carbonate units in the northeastern Brooks Range are common to the dolomitic rocks of these two areas. These features, the pisolitic and oolitic beds, and the dark laminated dolomites, are described in the lower 1,600 feet of the 3,400-foot succession of Katakturuk Dolomite in the Shublik Mountains (Dutro, 1970). In addition to the probability that the upper part of the Katakturuk is missing in the mapped area, the Nanook Limestone, a Middle(?) Devonian unit 3,000 feet thick which overlies the Katakturuk Dolomite in the Shublik Mountains (Dutro, 1970), is also absent in the Romanzof Mountains. This very thick missing section is probably the result of the major erosional hiatus preceding deposition of the Kekiktuk and Kayak(?) units and suggests, that if the rocks in this region are structurally autochthonous, the Romanzof Mountain area was a positive area relative to the Shublik Mountains in Late Devonian time. The presence in the Old Man Creek area of sandstone, siltstone, and thick sedimentary breccias suggests that during deposition of the Katakturuk, the Romanzof Mountain area was probably a shoal area and perhaps nearer shore than the area of the Shublik Mountains.

The Katakturuk Dolomite was suggested to be in part at least Middle Devonian in age, but may include beds as old as Cambrian (Dutro, 1970). In the area of this report, no fossils other than scattered crinoid columnal segments were found in the Katakturuk.

MISSISSIPPIAN SYSTEM

KEKIKTUK CONGLOMERATE AND KAYAK(?) SHALE

NAMES AND DEFINITIONS

The Kekiktuk Conglomerate was defined as an Upper (?) Devonian or Mississippian unit of quartzitic chert-pebble conglomerate and gray sandstone, 295 feet thick, which overlies the Neruokpuk Formation and underlies Kayak(?) Shale near Lake Peters, 15 miles west of the Romanzof Mountains (Brosgé and others, 1962, p. 2185). Probable correlatives are widely distributed but locally absent eastward from the Canning River to the Alaska-Yukon boundary.

The Kayak Shale was originally defined in the central Brooks Range as a Lower Mississippian unit of black shale and sandstone, 960 feet thick, which disconformably overlies the Kanayut Conglomerate and disconformably underlies the Wachsmuth Limestone of the Lisburne Group (Bowsher and Dutro, 1957, p. 6). In the eastern Brooks Range, a similar black shale overlies the Kekiktuk Conglomerate, the Katakturuk Dolomite, the Nanook Limestone, and the Neruokpuk Formation. This was termed Kayak(?) Shale (Brosge and others, 1962, p. 2185) because its physical continuity with the type Kayak has not been established.

In the present report, dark shale, slate, and minor limestone directly underlying the Lisburne Group are referred to the Kayak(?) Shale, and the underlying coarser clastic rocks with interbedded shale are referred to the Kekiktuk Conglomerate. They are mapped as one unit (pl. 1) which was previously called Kayak Shale (Sable, 1959, p. 26–35; Bunnell, 1959, p. 24–30).

DISTRIBUTION AND OUTCROP

Sporadically exposed around the periphery of the area, the Kekiktuk Conglomerate and Kayak(?) Shale crop out in narrow bands adjoining the belts of younger Lisburne Group rocks. Where well exposed, they form a distinctive marker unit between Lisburne and older rocks. Rocks ascribed to the Kekiktuk Conglomerate are dominant east of the Okpilak River and locally along Old Man Creek drainage, where they form cliffs and areas of angular brightly ironstained rubble. Where resistant rocks are absent or thin, the map unit forms benches and swales between resistant Lisburne and Neruokpuk rocks. On aerial photographs, exposures of this unit are not distinctive except for their contrast with light-hued carbonate units.

LITHOLOGIC CHARACTER AND THICKNESS

The Kekiktuk Conglomerate and Kayak(?) Shale consist mostly of epiclastic rock types ranging from boulder conglomerate to clay shale. Measured sections 5 and 6 along the Okpilak River and Old Man Creek indicate the variability of rock types in the unit. In the eastern part of the area light-colored sandstone and quartzite with minor conglomerate are dominant; west of the Okpilak River, rocks are generally darker and locally contain higher proportions of shale as well as coarse conglomerate.

Sandstone, granule conglomerate, and quartzite are very light gray to dark gray and they weather yellowish gray to dark gray; they are commonly medium to coarse grained and are generally well sorted with respect to size. They are nearly monomineralic, consisting of well-packed, subround to subangular quartz grains with a few heavy resistate and chert grains. The matrix, which constitutes 10–30 percent of these rocks, is mostly quartz and calcite; carbonaceous material is present in the darker varieties. The thickness of blocky to massive beds averages about 4 feet and is as much as 15 feet; the thickness of resistant sets of beds is as much as 80 feet. The rock is evenly bedded, uniform to banded, and crossbedding, where seen, is of low angle. Few sharp contacts were observed between beds.

Very fine-grained sandstone and siltstone, though not common, occur as transitional units between sandstone and shale. Silty and clayey shale is medium gray to black, commonly carbonaceous, and occurs in sets of beds whose thickness averages 1–2 feet but is as much as 15 feet. Macerated coaly plant fragments are locally abundant. Some shale grades to argillaceous sandstone in which medium- to coarse-sized quartz grains are poorly packed.

Bunnell (1959, p. 24–29) described the Kayak Shale (Kekiktuk and Kayak(?) unit of the present report) in the area of Old Man Creek (measured section 6). There it consists of quartzite, shale or slate and argillite, pebble to boulder conglomerate in the lower part and shale with interbedded sandy to shaly limestone in the uppermost beds. Lenses of coarse conglomerate as much as 20 feet thick are well exposed along Slippery Creek. Conglomerate constituents are poorly sorted round to subangular fragments of quartzite, schistose quartzite, vein quartz, phyllite, and slate (probably derived from the Neruokpuk Formation) in a shale and sandstone matrix. At one locality along this tributary the basal 15 feet of the unit is carbonaceous shale in which are interbedded 1- to 2-foot-thick tabular blocks of limestone similar to limestones in the underlying Katakturuk Dolomite. These are interpreted to be blocks of the older unit incorporated in Kekiktuk and Kayak(?) rocks, but may represent upper beds of the Katakturuk.

In most localities, relatively clean sandstones of the Kekiktuk and Kayak(?) have been metamorphosed to quartzite and schistose quartzite, and more argillaceous varieties to quartz-muscovite and quartz-sericite schist. Most shales have been metamorphosed to slate or phyllite. In addition, pyrite and iron oxides are locally common.

The Kekiktuk and Kayak(?) unit is highly variable in thickness, ranging from perhaps 0 to about 400 feet; the greater thicknesses are mostly due to the presence of the coarser grained rocks. The unit is locally very thin or possibly absent, because carbonate rocks mapped as Lisburne Group appear to rest on pre-Mississippian units at some localities where rubble-covered intervals as small as 10 feet occur between Lisburne rocks and the underlying Neruokpuk Formation, Katakturuk Dolomite, or granite. Apparent thicknesses of Kekiktuk and Kayak(?) along the Jago River range from 40 to 200 feet, but there the position of the basal contact with underlying schistose metasediments and granite is not well defined. From the Jago River to 3 miles west of the Okpilak River schistose rocks thought to be metamorphosed Kekiktuk and Kayak(?) adjoin the north front of the granite body, and they appear to range in thickness from a few feet to at least 100 feet. In the vicinity of Old Man Creek and the Hulahula River, sections are as much as 120 feet thick and average about 50 feet, but locally the unit is extremely thin or may be absent.

The Kayak(?) Shale appears to be thicker and more variable in the southwestern part of the area. There, at least 300 feet of Kayak(?) is dominantly dark-gray to black shale interbedded with two or more lenticular units of dark-gray silty limestone as much as 30 feet thick, at least one bed of metamorphosed coal several inches thick, and thin beds of dark-gray quartzitic sandstone. Kekiktuk beds are discontinuous and generally thin in this part of the area, but the lower part of the overlying Lisburne Group, consisting of dark-gray shaly limestone, shale, and black chert, appears to be well developed here.

STRATIGRAPHIC RELATIONSHIPS AND DEPOSITIONAL CHARACTER

The Kekiktuk Conglomerate and Kayak(?) Shale overlie metasedimentary rocks of the Neruokpuk Formation and Katakturuk Dolomite with angular unconformity. This relationship is best exposed on a small scale west of the Okpilak River along Old Man Creek (Bunnell, 1959, p. 29) and along the Jago River, 12½ miles south of Jago Lake (pl. 1). Bedrock contacts at the base of the Kekiktuk and Kayak(?) were not seen east of the Okpilak River, except where schistose rocks of the unit overlie schistose granitic rocks and the contact appears to be gradational. Throughout the general area, however, the unit rests on several older metasedimentary units, and aerial photograph studies east of the area (Brosgé and others, 1962, p. 2183–2184; Reiser and Tailleur, 1969) show distinct angular relationships between the Kekiktuk and Kayak(?) unit and the Neruokpuk. The unconformity represents one of the major tectonic and erosional hiatuses recorded in the Brooks Range. It is not known whether the Kayak(?) and Kekiktuk are separated by a disconformity; if so, the hiatus represented was of small magnitude. My impression is that the two are vertically and laterally gradational with one another in this area.

Deposits of the Kekiktuk Conglomerate indicate the beginning of shelf deposition which persisted through the remainder of Paleozoic time. Shale, with abundant carbonaceous material, coal, and coarse clastics which, except for the coarsest conglomerates, are relatively clean and well sorted, is interpreted to represent nonmarine or marginal marine deposits of strandline, swamp, and lagoonal origin. The monomineralic nature of the sand-sized deposits suggests that considerable reworking took place prior to deposition. The planar beds imply sheetlike spreading of sand. The pebble to boulder conglomerates in the northwest part of the area may be products of torrential streams which debouched southward into swampy or lagoonal environments.

Gradational relationships between the Kayak(?) Shale and Lisburne Group are indicated by an increase in carbonate and sand grains in the uppermost part of the Kayak(?) in the northern part of the area, and by the lithologic similarity of Kayak(?) and dark basal Lisburne rocks in the southern part of the area. Virtually continuous deposition of dark muds during Kayak(?) time with a gradual shift to carbonate deposition and influx of minor sand from a northern source across the Kayak(?)-Lisburne boundary is suggested.

CORRELATION AND AGE

Correlation of coarse-grained rocks of the map unit in the mapped area with the type Kekiktuk Conglomerate is based on similarities in lithology and stratigraphic position. The fine-grained rocks of the map unit in most exposures closely resemble the Kayak(?) Shale in the vicinity of Lake Peters. In the western Romanzof Mountains, however, a satisfactory distinction between the two formations is not everywhere possible because fine and coarse clastics interfinger in the lower and middle parts of the Kekiktuk and Kayak(?) unit. If the unit is subdivided on a lithologic basis, and no erosional breaks exist within the unit, most of the unit west of the Okpilak River should properly be referred to the Kayak(?), with lateral interfingering eastward to the Kekiktuk.

Rocks of similar character and stratigraphic position have been reported in other areas of northeastern Alaska east, west, and south of the Romanzof Mountains (Gryc and Mangus, 1947; Mangus, 1953; Whittington and Sable, 1948), where they were referred to as the Kayak Shale or the Noatak Formation; the Noatak is now restricted to rocks farther west (Bowsher and Dutro, 1957, p. 3). Brosgé, Dutro, Mangus, and Reiser (1962) portrayed several Kayak, Kayak(?), and Kekiktuk sections and also depicted the regional character and thickness of the Kanayut Conglomerate, a unit of Late Devonian age as much as 5,000 feet thick which underlies the Kayak Shale in the central and east-central Brooks Range.

The Kekiktuk Conglomerate was assigned a Mississippian age by Reiser (1970). As suggested by Brosgé, Dutro, Mangus, and Reiser (1962), it may represent a basal conglomerate facies which, with the younger Kayak(?), overlaps older units and crosses time lines northeastward. If the Kekiktuk was continuous with the Upper Devonian Kanayut Conglomerate, the basal beds of both may also be inferred to progressively overlap onto an Upper Devonian unconformity in the northeastern Brooks Range (Brosgé and others, 1962, p. 2185).

The locally abundant plant fragments, mostly in the lower part of the Kekiktuk and in coaly Kayak beds, are poorly preserved and indeterminate. The type Kayak Shale, central Brooks Range, contains marine invertebrates of Early Mississippian age. In the northeastern Brooks Range, an Upper Mississippian lithostrotionoid coral is reported in the upper part of the Kayak(?) near Lake Peters (Brosgé and others, 1962, p. 2186). In the Romanzof Mountains area, the Kayak(?) grades upward into the Alapah Limestone of the Lisburne Group which contains lithostrotionoid and syringoporoid corals of probable Late Mississippian age. South of Kolotuk Creek, syringoporoid corals occur in limestones in the lower part of the Kayak(?). If the Kayak and Kayak(?) represent a continuous sedimentation unit ranging in age from Early to Late Mississippian, then the unit apparently represents deposition along the shores of an eastward- or northward-transgressing sea.

Rocks along the Alaska-Yukon boundary reported by Maddren (1912, and unpub. data) and Mangus (1953, p. 14) appear to be similar in position and lithology to but are thicker than the Kekiktuk, Kayak, and Kayak(?) units farther west. Estimated thicknesses of the eastern exposures are 600–1,000 feet. Invertebrate fossils from one locality were tentatively identified by Mangus, who called the entire unit Kayak Shale.

Martin (1959, p. 2421), in discussing rocks of the Yukon Territory and northeastern Alaska, referred the Kayak as used by Mangus to the Devonian (probably Upper Devonian) and apparently believed Mississippian rocks to be the predominantly carbonate and shaly sequences overlying the coarser clastics. According to this interpretation, Upper Devonian nonmarine clastic rocks which are more than 6,000 feet thick and which indicate a southeastward-debouching delta in the southern Richardson Mountains, Yukon Territory (Martin, 1959, p. 2443), are roughly equivalent to the Kekiktuk Conglomerate, just as the thick Kanayut Conglomerate of the central Brooks Range may be roughly equivalent. Whether or not these clastic rocks are true equivalents, they are broadly contemporaneous and represent clastic deposition from a major area of uplift. The Romanzof Mountains lie in a belt in which the clastic rocks of the Kekiktuk Conglomerate are very thin compared with those in areas to the southwest and southeast and away from which the Yukon Territory clastics and Kanayut rocks become finer grained. The base of the Kekiktuk represents a major unconformity. The area of the Romanzof Mountains, therefore, is interpreted to have been located in or marginal to a positive belt, possible one of orogenic activity during the Late

Devonian. This interpretation is discussed under "Tectonics" in the present report.

MISSISSIPPIAN AND PENNSYLVANIAN SYSTEMS

LISBURNE GROUP

NAMES AND DEFINITION

Schrader (1904, p. 62–67) named a sequence of dominantly light-gray limestone exposed along the Anaktuvuk River, central Brooks Range, the Lisburne Formation. Leffingwell (1919, p. 105–108) referred to similar rocks in northeastern Alaska as the Lisburne Limestone. Subsequently, detailed studies in the Shainin Lake area, 170 miles southwest of the Romanzof Mountains, resulted in this carbonate sequence being raised in rank to group, which consisted of two formations (Bowsher and Dutro, 1957, p. 6). The lower formation, the Wachsmuth Limestone (Lower and Upper Mississippia), 1,230 feet thick, consists of banded dolomitic, bioclastic, crinoidal, and shaly limestones, and minor chert. The upper formation, the Alapah Limestone (Upper Mississippian), 970 feet thick, is subdivided into nine members containing clastic limestone, silicified limestone, shale, chert, and oolitic limestone. The upper four members generally light colored, are separated from the lower four, dark-colored, members by a black chert-shale member. The Alapah is disconformably or unconformably overlain by Lower(?) Permian Siksikpuk Formation at its type locality.

Brosgé, Dutro, Mangus, and Reiser (1962, p. 2187–2190) extended these two formations eastward from their type localities into the eastern Brooks Range. Pertinent to the present report is the fact that the Wachsmuth Limestone thins eastward, apparently as the result of loss of its upper part, and finally is entirely absent near Lake Peters, 15 miles west of the Romanzof Mountains. The Alapah Limestone thickens east-northeastward at least to the Lake Peters locality and is also thicker south of the Romanzof Mountains. In the eastern Brooks Range, the Alapah is overlain by the Wahoo Limestone (Brosgé and others, 1962) of Late Mississippian and Early Pennsylvanian age (Armstrong and others, 1970), which is also included in the Lisburne Group.

In the Romanzof Mountains, the predominantly limestone sequence between the Kayak(?) Shale and the Sadlerochit Formation were referred to as the Lisburne Group (Sable, 1959, p. 46; Bunnell, 1959). These rocks were considered to be Wachsmuth lithologic equivalents, partly because of the abundance of crinoidal limestone in their upper part. Later investigations (Brosgé and others, 1962) suggest to me that the crinoidal limestones in the upper part of the Lisburne in the Romanzof Mountains represent the Wahoo Limestone. In the present report the lower part of the Lisburne Group is termed Alapah Limestone and the upper part Wahoo Limestone; the two units are mapped together on plate 1.

ALAPAH LIMESTONE

DISTRIBUTION AND OUTCROP

East of the Okpilak River, the Alapah Limestone crops out along the north front of the granitic pluton and locally rests on mountains made up largely of the granite. This belt extends across the Jago River and continues eastward as a series of east-striking ridges along the front of the mountains. Farther south, a north-striking belt lies along the west side of the Jago River, and the southernmost known exposures lie in an east-northeast-striking belt east of the river. Isolated patches of Alapah also occur along the southern margins of the main granite body between Jago and Okpilak Rivers.

West of the Okpilak River, Alapah Limestone is exposed in a west-southwest-striking and structurally complex linear belt along the north front of the granite, essentially continuous with the eastern belt. Farther north, mountainside exposures of Alapah covering a large area are common in Old Man and Esetuk Creek drainages and along the Hulahula River valley. West of Mount Michelson, the Alapah comprises large areas of exposure along the western margin of the granite.

The Alapah Limestone is a resistant and structurally competent unit in the Romanzof Mountains. Good exposures are common in cliffs along steep mountainsides or as massive ledges projecting through rubble. The light-gray-weathering colors of the unit in the northern part of the area make it distinctive and easily recognized, both on the ground and as seen on photographs (fig. 21). These outcrops can be confused with the Katakturuk Dolomite, which weathers, however, in pinnacles and ragged cliffs of lighter hues. Exposure belts of Alapah Limestone in the southern and western parts of the area weather to darker colors and are not easily identified from a distance or on photographs.

LITHOLOGIC CHARACTER AND THICKNESS

Carbonate rocks make up about 90 percent of the Alapah Limestone in the Romanzof Mountains and include sandy, crystalline, and silicified limestone, dolomite, and minor crinoidal limestone. Chert, shale, limy sandstone, and quartzite are less common. Two somewhat different sequences characterize the Alapah in the northern and southern parts of the area.

In the northern part of the area, the lower part of the Alapah is characterized by arenaceous carbonates and is called the sandy limestone unit; the upper part, mostly dark-gray fine-grained carbonate rocks, is the dark carbonate unit. The sandy limestone unit consists of arenaceous and silty limestone to medium-grained crystalline limestone interbedded in some sections with minor amounts of dark-gray shale, quartzite and sandstone, and thin quartz- and chert-granule to pebble conglomerate in limestone matrix. The limestone is commonly light to medium gray, blocky to massive, and well consolidated to friable, and it contains scattered dark- and light-gray chert nodules. Some beds contain abundant crinoidal debris, and sandy limestone is commonly crossbedded. One or more zones of spheroidal sandy chert concretions occur in the upper part of this unit. In parts of the area, such as Okpirourak Creek

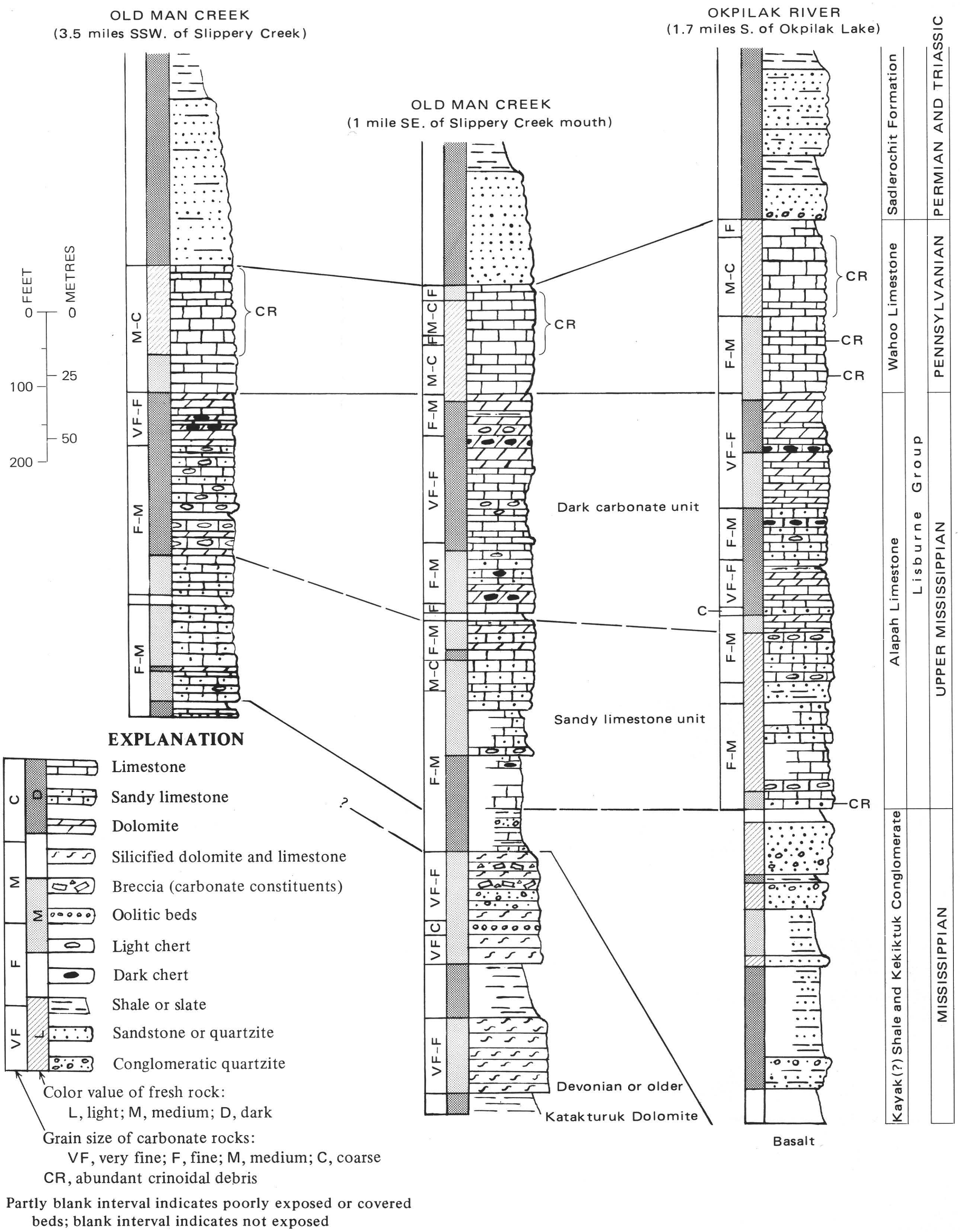


FIGURE 4.—Columnar sections of the Lisburne Group and older and younger units in northern part of Romanzof Mountains. See measured sections 6, 7, 8, and 9 for lithologic descriptions.

drainage, basal Alapah beds of pebble and granule conglomerate with subangular to subround grains of quartz, chert, and limestone are as much as 3 feet thick. The upper dark carbonate unit of the Alapah contains about 30–40 percent dolomite and dolomitic limestone interbedded with limestone. The dolomite is dark to light gray, weathers grayish orange and yellowish orange or dark gray, is very finely saccharoidal to sandy in texture, locally thinly cross-laminated, and occurs in beds commonly less than 1 foot thick but as much as 5 feet thick. Interbedded silty to crystalline, platy to slabby limestone is commonly darker than the dolomite and generally less sandy than limestones in the sandy limestone unit; it also includes sublithographic and minor phosphatic(?) types. Minor dark-gray shale beds and nodules and thin lenses and beds of dark chert in limestone units are subordinate but characteristic features of this part of the Alapah. Although the carbonates are generally thin bedded, some units are very thick and massive. The lithology of the Alapah in the northern part of the area is shown in figure 4 and described in measured sections 5, 7, 8, and 9.

In the southern part of the area, roughly south of lat 69°21′ N., an estimated several hundred feet of dark-gray to black limestone, chert, shale, and minor dolomite makes up the basal part of the Lisburne Group. Because they contain lithostrotionoid corals and carbonate rocks are dominant, these strata are included in the Alapah Limestone; they are termed the black cherty unit. This unit, extimated to be at least 400 feet thick, lies between dark shale of the Kayak(?) Shale and rocks which resemble the sandy limestone unit of the Alapah. The black cherty unit contains carbonate beds which are probably phosphatic, judging from the bluish efflorescence on outcrop faces, and it locally contains common lithostrotionoid and syringoporoid corals.

Thin sections from the Alapah Limestone indicate some silicification similar to that in the Katakturuk Dolomite, but most of these rocks are calcitic and do not have pronounced metamorphic textures. Some dolomite occurs as rhombs; scattered floating grains of quartz and chert are also present. Ferric oxides are locally common.

Thicknesses of the Alapah Limestone vary considerably within the area. In the northern part of the area, they are about 560 feet along the Okpilak River, range from 410 to 500 feet between the Okpilak and Hulahula Rivers, and some sections adjoining granitic rocks east of the Okpilak River are less than 200 feet thick. In the southern part of the area the Alapah is thicker, perhaps 1,200 feet or more thick, largely because the black cherty unit is present at the base of the formation. Possible reasons for the thickness variations in the northern part of the area include (1) depositional thickness variations or disconformity within the Alapah, (2) erosion prior to deposition of Wahoo Limestone or Sadlerochit Formation, (3) unrecognized faulting, (4) the equivalence of Kayak(?) Shale in parts of the area to basal Lisburne rocks exposed elsewhere, and (5) deposition of Alapah Limestone on an irregular terrain. I believe that gross thickness variations within the Alapah in the northern part of the area are mainly due to depositional thickness variations within the dark carbonate unit and in part due to pre-Sadlerochit erosion. The dark carbonate unit ranges in thickness from about 150 to 300 feet; the sandy limestone unit ranges from only about 250 to 300 feet. The contact between the two units appears to be abrupt in most sections, but in some places sandy limestones in the lower part of the upper unit suggest gradational or intertonguing relationships. The base of the overlying Wahoo Limestone, however, appears to maintain a fairly consistent position relative to orange-weathering dolomites in the uppermost part of the Alapah and to dark cherty beds 40–70 feet below the Wahoo (fig. 4). Where the Sadlerochit Formation overlies Alapah rocks, an erosional hiatus is strongly indicated. No firm evidence for the other possibilities regarding Alapah thickness changes was noted during field studies. The abnormally thin sections adjoining granitic rocks, however, are probably faulted.

Sections of the Lisburne Group along the Jago River are structurally too complex for confident thickness estimation. The southernmost belt east of the river, however, covers a broad area, and aerial photograph thickness estimations in this belt 3–10 miles east of the Jago River indicate that thickness of the Lisburne Group may exceed 2,000 feet. Both east and west of the Romanzof Mountains, the Lisburne Group and Alapah Limestone are reported to be thicker than in the area of this report. On the Kongakut River, 50 miles to the east-southeast, the Alapah Limestone is more than 1,580 feet thick and the overlying Wahoo more than 1,330 feet thick (Brosgé and others, 1962, fig. 5, p. 2187). West of the Romanzof Mountains, on the west side of the Hulahula River, the Lisburne Group is at least 600 feet thick and perhaps as much as 1,000 feet thick (C. L. Whittington and E. G. Sable, unpub. data, 1960). Near Lake Peters, 15 miles west of the mountains, the Alapah is 1,378 feet thick and the Wahoo is 447 feet thick; on the Sheenjek River, about 60 miles south of the mountains, the Alapah is at least 1,360 feet thick (Brosgé and others, 1962). In the Sadlerochit Mountains, northwest of the Romanzof Mountains, the Alapah is at least 1,100 feet thick (C. L. Whittington and E. G. Sable, unpub. data, 1960). The Alapah, except in the north and northeast where its subsurface thicknesses are unknown, apparently thins rather abruptly, at least from the east and west, toward the Romanzof Mountains, and it thins abruptly northward within the area of this report.

STRATIGRAPHIC RELATIONSHIPS AND DEPOSITIONAL CHARACTER

Contacts between the Alapah Limestone and Kayak(?) Shale seem to be gradational. In an exposure about 3 miles south of Okpilak Lake, shaly sandstone of the Kayak(?) grades into massive sandy limestone of the Alapah within a few stratigraphic feet. Several feet above the contact, beds of sandy limestone are interbedded with massive finely crystalline to silty limestone. Sandy beds diminish upward in the section. Farther south, the contact between the black cherty unit of the Alapah and the Kayak(?) Shale suggests gradation because both formations contain similar limestone and shale and the contact there is approximated on relative abundances of these rock types. No important stratigraphic breaks were recognized within the Alapah in the Romanzof Mountains. Some irregular bedding contacts and intraformational conglomerates are present, but their significance is not known.

The Alapah underlies the Wahoo Limestone in most of the Romanzof Mountains area west of the Jago River. Exceptions are the belt adjoining the north side of the granite and a few places in Old Man Creek drainage (Bunnell, 1959, p. 38) where the Wahoo Limestone is missing, and the Sadlerochit Formation directly overlies the dark carbonate unit of the Alapah.

Mississippian seas, encroaching perhaps from the southwest, are interpreted to have reached the Romanzof Mountains area at a later date than in the central Brooks Range (Sable, 1959, p. 47–48; Brosgé and others, 1962, p. 2185). The Kekiktuk, Kayak(?), and Alapah may be interpreted to represent time-transgressing units in which successively diminishing amounts of terrigenous material were shed from a probable northern source. Cross-bedding, sandy character, relatively abundant faunal remains, and light colors in the sandy limestone unit of the Alapah indicate a shallow shelf-type environment with moderate current activity. The darker generally finer grained and sparsely fossiliferous dolomitic rocks in the dark cherty and upper dark carbonate units of the Alapah may indicate a deeper or more restricted hypersaline environment. If no major structural juxtaposition of facies has occurred in the area, a hinge line roughly along lat 69°21′ N. which separated a deeper basin to the south from a shelf area to the north is suggested by the distribution of the dark cherty unit of the Alapah.

AGE AND CORRELATION

Marine invertebrates in the Alapah Limestone of the Romanzof Mountains are locally abundant but distorted, fractured, and so completely replaced by quartz or calcite that for the most part not even genera can be identified. Crinoid columnal segments are the most abundant forms. Brachiopods, including spiriferoid and productid types, are poorly preserved, as are questionable pelecypod shells. Corals, including colonial lithostrotionoid, syringoporoid, and solitary types are better preserved, being crudely silicified, though much distorted. Fossil collections from the area have been identified by J. T. Dutro, Jr., and Helen Duncan of the U.S. Geological Survey. Those in strata referred here to the Alapah Limestone are shown in table 3; most, if not all of the collections are from the sandy limestone unit.

Concerning the corals from the Alapah Limestone of this area, Helen Duncan stated (written commun., 1960):

> None of the corals from beds assigned to the lower part of the Lisburne Group in this area are types known from the central Brooks Range. The occurrence of the solitary corals suggestive of *Faberophyllum*, of lithostrotionoids, particularly the phaceloid form identified as *Siphonodendron*? (USGS 19570-PC), and of a *Syringopora* (USGS 19567-PC) comparable to a species that occurs in the lower Alapah are interpreted to indicate that most of the lower Lisburne in your area is of Late Mississippian age and probably equivalent to the lower part of the Alapah Limestone.

J. T. Dutro, Jr., added (written commun., 1960):

> The few other fossils in these collections also suggest correlation with the lower Alapah. *Gigantoproductus* occurs with lithostrotionoid corals in many places in the lower part of the Alapah Limestone where it has been examined in the eastern Brooks Range.

During field studies, I identified lithostrotionoid and syringoporoid corals from several other places within 100 feet of the base of the sandy limestone unit and within 50 feet above the base of the lower dark cherty unit. Lithostrotionoid corals reported within 50 feet of the top of the Lisburne (Sable, 1959, p. 47), now considered to be from the Wahoo Limestone, are apparently a new genus of unknown age affinities (table 4). Field identifications of *Gigantoproductus* at several localities but at unknown stratigraphic positions were also made.

From the above evidence, the Alapah Limestone in the Romanzof Mountains is considered to be entirely Late Mississippian in age. The dark carbonates, dolomitic beds, and dark chert in the upper dark carbonate unit of the Alapah appear to be similar to those in sections of Alapah Limestone elsewhere in the eastern Brooks Range described by Brosgé, Dutro, Mangus, and Reiser (1962).

TABLE 3.—*Fossils from the Alapah Limestone, Romanzof Mountains*
[Identifications by J. T. Dutro, Jr., and Helen Duncan]

Locality (pl. 1)	Field No.	USGS Colln. No.	Stratigraphic position above base (ft)	Identification
Old Man Creek	58ASa131(4)	19566-PC	5–10	*Fenestella* sp., *Echinoconchus* sp., *Spirifer* aff. *S. tenuicostatus* Hall, Fish tooth, indet.
Jago River	57ASa56	19567–PC	0–10	Lithostrotionoid coral, genus indet. *Syringopora* cf. *S.* aff. *S. hyperbolo-tabulata* Ch. (occurs in lower Alapah (USNM loc. 3087) in central Brooks Range).
Old Man Creek	58ASa131(3)	19568-PC	10–20	Horn coral, indet.
Do	58ASa131(2)	19569-PC	20–30	Horn corals, indet. (fragments suggestive of *Faberophyllum* complex).
Okpirourak Creek headwaters.	58ASa20	19570-PC	50+	*Siphonodendron*?, sp. indet. (preservation very poor).
Tributary of Hulahula River.	58ASa154a	19571-PC	0–50(?)	*Faberophyllum*?, sp. indet., *Fenestella* sp., Brachiopod fragment, indet.
Old Man Creek	58ASa145	None	0–100	Cephalopod?, indet.
Jago River	57ASa53	19572-PC	0–100	*Gigantoproductus*, sp. indet., Bellerophontacean gastropod, indet.
Tributary of Hulahula River.	58ASa160(1)	19573-PC	(?)	*Faberophyllum*? sp.
Jago River	57ASa81	19574-PC	(?)	*Siphonodendron*, sp. indet.

The sandy quartzose character of the limestones in the sandy limestone unit, however, does not seem to have identical lithic counterparts in sections shown by them, although Mangus (1953, p. 15) reported arenaceous limestone and black shale in the lower 500 feet of the Lisburne on Joe Creek, near the Alaska-Yukon boundary. Sandy material may have originated from a northern source area or from local sources within the area. Strata of the dark cherty unit are identical to the upper part of the Kayak(?) Shale described in the Lake Peters area (Reed, 1968, p. 35–36).

WAHOO LIMESTONE

NAME AND DEFINITION

The uppermost formation of the Lisburne Group in the eastern Brooks Range is the Wahoo Limestone (Brosgé and others, 1962, p. 2190–2192). The Wahoo occurs at almost all eastern Brooks Range Lisburne localities, where it is divided into two members. The lower member, present in all sections examined, is characterized by medium- to light-gray, coarse-grained to lithographic limestone and differs from the underlying Alapah Limestone mainly in that it does not contain dark carbonate rocks. The upper member consists mostly of coarse-grained crinoidal limestone with interbedded shale and shaly limestone and is distinguished by a zone of black nodular chert at its base in most sections. The Wahoo is unconformably overlain by the Permian and Triassic Sadlerochit Formation in its eastern exposures and by the Lower(?) Permian Siksikpuk Formation farther west beyond the report area. The Wahoo is considered to be Mississippian and Pennsylvanian.

The upper part of the Lisburne Group as used by Sable (1959) and Bunnell (1959) is here termed Wahoo Limestone on the basis of lithologic similarity and position relative to the underlying dark carbonate unit of the Alapah Limestone and the overlying Sadlerochit Formation. The faunal character in collections made from these rocks is apparently not diagnostic.

OUTCROP, LITHOLOGIC CHARACTER, THICKNESS, AND RELATIONSHIPS

The Wahoo Limestone is exposed in the northern part of the area from Okpirourak Creek westward. It was not recognized in the east-northeast-trending belt which adjoins the northern margin of the granitic rocks or in a few places farther north. The upper part of the Lisburne Group was not examined east of the Jago River.

Crinoidal limestones in the Wahoo weather to light hues in contrast with the uppermost dark carbonate unit of the Alapah; this contrast is striking on some aerial photographs. Wahoo Limestone commonly weathers to cliffs and massive ledges and is locally friable.

The lower part of the Wahoo Limestone is dominantly medium- to very fine-grained gray limestone, weathers blocky to massive, and contains perhaps 10 percent lenses and beds of coarse-grained crinoidal limestone which increase in abundance upward. Coquinoid beds consisting mostly of bryozoan and brachiopod fragments were seen in a few exposures near the base. Chert and dolomite are absent or very minor.

Thick massive beds of bioclastic crinoidal limestone are distinctive units which comprise about 90 percent of the upper part of the Wahoo. They are light to medium gray, well consolidated to friable, and weather whitish to light gray, and slabby to massive. Medium-gray silty to very finely crystalline platy to flaggy limestone and very minor amounts of dolomite are also present in the uppermost part of the sequence; scattered chert nodules and lenses are not common. At least one zone of septarian concretions and sedimentary chert breccia is locally associated with crinoidal limestone.

Measured thicknesses of the Wahoo Limestone range from 40 to at least 200 feet. The crinoidal limestone occurs in sets of beds 40–130 feet thick. The thickness variation of the crinoidal limestone may result partly from intertonguing with the lower part of the formation, which apparently is 35–100 feet thick, but probably it is mostly the result of erosion prior to Sadlerochit Formation deposition. The Wahoo is absent in some localities, particularly in the belt adjoining the north side of the granite mass. In this belt, such as localities 5 miles southwest of Okpilak Lake, small infolded remnants of basal quartzites of the Sadlerochit Formation overlie dark limestones and dolomites of the upper dark carbonate unit of the Alapah.

The Wahoo appears to be conformable with the underlying Alapah Limestone, although rocks on either side of the contact are considerably different. The uppermost beds of the Alapah are mostly orange-weathering dolomites whereas those of the basal Wahoo are gray-weathering fossiliferous limestones.

AGE, CORRELATION, AND DEPOSITIONAL CHARACTER

Three invertebrate fossil collections from the Wahoo Limestone of this area are shown in table 4. These were identified by J. T. Dutro, Jr., and Helen Duncan of the U.S. Geological Survey.

In addition, Helen Duncan (written commun., 1960) remarked that "Few corals were obtained from the upper part of the Lisburne section [Wahoo of this report]. Those that do occur are types found in the later part of the Lower Carboniferous." The coral in 19175-PC is now considered to be the only one collected from the Wahoo. Another collection, 19574-PC containing *Siphonodendron*, sp. indet. (table 3), which was referred to by Duncan as being questionably in the upper part of the sequence, is almost certainly Alapah. Dutro (written commun., 1960) added that "The spiriferoid brachiopods suggest a correlation with higher parts of the Alapah Limestone, although

TABLE 4.—*Fossils from the Wahoo Limestone, Romanzof Mountains*
[Identifications by J. T. Dutro, Jr., and Helen Duncan]

Locality (Pl. 1)	Field No.	USGS Collection No.	Stratigraphic position	Identification
Okpilak River	57ASa124	19577-PC	Less than 100 ft below top.	*Fenestella*, 2 spp., Fenestrate bryozoan, indet. (apparently a genus with a coarse super-structure cf. *Isotrypa*).
Old Man Creek	58ASa138	19176-PC	Probably lower or basal part.	*Davidsonia*? sp. *Neospirifer*? sp. Pectinoid pelecypod fragment, indet.
Do	58ASa139	19175-PC	20 ft below top.	Echinodermal debris, indet. Colonial coral, cerioid dibunophyllid, probable new genus "*Dictyoclostus*" sp. *Neospirifer*? sp.

nothing diagnostic occurs in these collections." The Wahoo is considered to be Pennsylvanian in age in northeastern Alaska (Armstrong and others, 1970).

Rocks of the Wahoo Limestone in the Romanzof Mountains area resemble those described in the Wahoo by Brosgé, Dutro, Mangus, and Reiser (1962, p. 2191), particularly the coarse-grained crinoidal limestones of their upper member. Rocks like those in their lower member were not recognized with certainty in this area. Near Lake Peters, 15 miles west of this area, the lower member of the Wahoo was reported to be 447 feet thick and overlain by the Sadlerochit Formation (Brosgé and others, 1962). In the Romanzof Mountains it is uncertain whether the lower member is absent, present only in the lower 25–100 feet, or is represented by a dominantly crinoidal facies. Reed (1968, p. 42) reported only 200–300 feet of Wahoo(?) Limestone in the Lake Peters area. Further work between Lake Peters and the Romanzof Mountains is necessary to determine the possible equivalency of the rock units.

Like the Alapah Limestone, the Wahoo Limestone is thinner in the Romanzof Mountains area than in sections measured within 75 miles southeast and southwest, and it appears to lie along the north margin of an eastward-trending depositional basin (Brosgé and others, 1962, fig. 5d, p. 2187). In the Yukon Territory, Martin's observations (1959, p. 2425–2426; fig. 7, p. 2423; fig. 20, p. 2448) indicate more than 3,000 feet of Permian-Pennsylvanian rocks. These include Pennsylvanian limestones perhaps as much as 2,800 feet thick and Pennsylvanian-Permian marine clastics and minor limestones (in part Sadlerochit Formation equivalents?) perhaps 1,000–1,500 feet thick. Relationships of the carbonates and clastics are not known, but the thick carbonates occur along a projected trend of the eastward-trending Wahoo carbonate depositional basin. The carbonate and clastic depositional basin during Middle Pennsylvanian to Early Permian shown by Martin (1961, p. 448) is an elongate mildly negative area which strikes northeastward toward the Canadian Arctic Islands.

In the Romanzof Mountains, the lighter colored, bioclastic, and more massive lower part of the Wahoo contrasts with underlying dark Alapah rocks, indicating change from possible restricted to open-sea shallow-shelf conditions. Dominant crinoidal debris toward the top of the sequence is interpreted to be biostromal and probably reflects accumulation by transportation from crinoid banks. Little or no terrigenous material is present; foreland areas may have lain to the north or west.

PERMIAN AND TRIASSIC SYSTEMS

SADLEROCHIT FORMATION

NAME AND DEFINITION

The Sadlerochit Formation was first named the Sadlerochit Sandstone by Leffingwell (1919, p. 113–115) after the Sadlerochit Mountains, 15 miles northwest of the Romanzof Mountains. He defined the formation as overlying Lisburne Limestone and underlying the Shublik Formation, and as being composed of ferruginous sandstone or quartzite with a few conglomeratic layers.

Keller, Morris, and Detterman (1961, p. 177), in the Shaviovik-Sagavanirktok Rivers area 90 miles west of the Romanzof Mountains, divided the Sadlerochit into the Echooka Member of Late Permian age and the Ivishak Member of Early Triassic age. Brosgé, Dutro, Mangus, and Reiser (1962, p. 2194) used the term Sadlerochit Formation for all these rocks within the Brooks Range east of the Ivishak River. The formation overlies the Lisburne Group with unconformity at most places. Its relationships to the Siksikpuk Formation (Lower(?) Permian) (Patton, 1957, p. 41), exposed west of the Ivishak River, are not known. Detterman (1970a) studied the Sadlerochit in greater detail in 1969 and extended the Echooka and Ivishak Members to exposures as far east as the Okpilak River.

Sable (1959) and Bunnell (1959) in the Romanzof Mountains divided the Sadlerochit Formation in ascending order into the ferruginous sandstone, shale, and quartzite members. The terminology used in the present report is that of Keller, Morris, and Detterman (1961), modified here by the subdivision of the Ivishak Member into two units, the shale unit and the quartzite unit.

OUTCROP, LITHOLOGIC CHARACTER, AND THICKNESS

Exposures of the Sadlerochit Formation are extensive along the north front of the Romanzof Mountains in an east-trending belt which narrows eastward. The Ivishak Member forms gentle slopes and broad mountain tops throughout most of the outcrop belt; outcrops of the Echooka Member occupy narrower bands in the valley walls. Owing to the presence of poorly resistant shaly rocks and the fact that many of the hills composed of Sadlerochit Formation have not been recently glaciated, the exposures are mostly covered by residual rubble and talus. Good exposures of the Echooka Member lie on the mountainsides adjoining Okpirourak Creek, on the east side of the Okpilak River, and along Old Man Creek and its tributaries. In outcrop, the cliff-forming quartzites of the Echooka are highly iron stained. The quartzite unit of the Ivishak Member weathers to grayish hues, and stabilized rubble is largely covered by black lichens. On aerial photographs the formation has a blotchy two-toned appearance owing to the lichen covering and the light-reflecting shale in the rubble.

All Sadlerochit rocks in this area are terrigenous detrital types considered to have been deposited in a marine environment, and no carbonate rocks as such are included in the formation, although some sandstones are calcareous. Nearly all types have been subject to dynamic and low-grade metamorphism including silicification. The resulting quartzites and slates, however, are not so severely altered that their primary sedimentary features have been lost. Two sections of Sadlerochit Formation are described in measured sections 5 and 9.

ECHOOKA MEMBER

Along the Okpilak River, quartzite, quartzitic and limy sandstone and siltstone, and minor thin conglomeratic beds occur in two fairly uniform, massive cliff-forming units separated by a middle unit composed dominantly of medium-dark-gray shale and slate. The coarser clastic strata are argillaceous, in part glauconitic, and their ferruginous nature is due to disseminated grains of limonite and oxidized pyrite; they are generally medium dark gray, fine grained to silty, and occur in regular beds 6 inches to 9 feet thick. Pebble conglomerates consist of about 70 percent well-rounded gray chert and argillite clasts; rounded siliceous nodules and clay ironstone nodules are conspicuous in the lower few feet. Shaly beds less than 1 foot thick are present. Abundant but poorly preserved fossil molds and casts occur throughout most of the lower unit and are most abundant in its basal part. Fossils are sparse in the middle and upper units. Pyritic concretions occur in all three units.

In thin section, sandstones are orthoquartzites consisting of closely packed, well-sorted subangular quartz and minor chert grains in cement of microcrystalline quartz, iron oxides, sericite, and calcite.

The three-unit subdivision of the Echooka Member characterizes exposures along the Okpilak River and Okpirourak Creek, but is not valid throughout the area. Exposures along the Jago River valley are too poor to permit recognition of this subdivision. Along Old Man Creek and Hulahula River drainages many sections indicate that the member has a variable sand-clay content; cliff-forming quartzitic rocks comprise the entire member in some places, whereas in others shale, slate and quartzite are interbedded throughout its middle and upper parts. The thickness of the Echooka Member is 175–240 feet and averages about 200 feet.

IVISHAK MEMBER

SHALE UNIT

The lower shale unit of the Ivishak Member consists of medium-dark-gray to black mostly silty shale and 10–20 percent thin interbedded quartzite. The shale is uniform, laminated, and banded, with beds a fraction of an inch to 1½ inches thick and sets of beds as much as 30 feet thick. A few 1- to 2-inch-thick beds of nodular clay ironstone are interbedded with the shales, and disseminated pyrite crystals are relatively common, particularly in black sooty shales. Quartzites are medium gray, in part laminated, regularly bedded, mostly less than 1 foot thick, and they weather pale yellowish brown. The quartzites also resemble those in the overlying quartzite unit of the Ivishak Member.

Thicknesses given for the shale unit are estimates. The unit is relatively incompetent and has yielded to deformation mainly by flowage; as a result, apparent thicknesses of the section vary considerably. In addition, the shale unit grades upward into the quartzite unit and therefore the contact between the two has probably not been drawn at the same depositional horizon in all parts of the area. The thickness of the shale unit between the Jago and Hulahula Rivers probably averages about 400 feet, but it ranges from 200 to 650 feet. Farther south, in the southernmost exposures at the head of Old Man Creek, the unit appears to be several hundred feet thicker (Bunnell, 1959, p. 42). The apparent southward increase in thickness may be in part due to southward decrease in grain size of the upper unit of the Echooka Member, which seems thin in this vicinity, or to structural duplication of shale unit sections. Structural duplication was considered likely during field studies, although no evidence for dislocation was recognized in this vicinity. Rocks of the unit are monotonously similar, and the unit contains no known key beds.

QUARTZITE UNIT

Quartzite, lesser amounts of shale and lime sandstone, and small amounts of granule-to-pebble conglomerate granule-to-pebble breccia, and clay ironstone constitute the upper quartzite unit of the Ivishak Member. Consisting largely of resistant beds which uphold high ridges and hills, quartzite makes up about 80 percent of the unit. The quartzite is medium gray to medium dark gray, fine to very fine grained, dense, apparently well sorted and clean, and weathers to grayish and brownish hues. Beds are even; they average about 2 feet in thickness and are as much as 10 feet thick, and they weather to massive, blocky, or platy fragments. Resistant sets of beds are as much as 50 feet thick. Texture is uniform to laminated, and beds locally contain symmetrical but irregular ripple marks of small amplitude and have scattered pelecypod molds on their surfaces. In thin section the quartzites show good sorting and close packing of angular to rounded grains composed of quartz (40–50 percent), chert (40–60 percent), and very fine grained dark rock fragments. Locally, heavy resistates compose as much as 5 percent of the rock and include euhedral to well-rounded zircon, and epidote, sphene(?), tourmaline(?), rutile, and garnet. Quartz overgrowths on quartz grains are locally common. Cement (5–10 percent) is mostly microcrystalline quartz, chlorite, and sericite.

Gray to black shale and slate, similar to that in the underlying shale unit, are interbedded with quartzite and occur in sets of beds commonly less than 1 foot thick. Pale-brown fine-grained limy sandstone occurs in 6-inch- to 2-foot-thick beds. The upper 100(?) feet of the unit is flaggy and ripple marked and it contains a few pelecypod molds; quartzitic conglomerate occurs as beds and lenses less than 1 foot thick and is apparently restricted to the upper part of the member. Conglomerate constituents are round to subround, fairly well sorted but poorly packed pebbles and granules of gray and black chert, milky quartz and other siliceous rock fragments, and minor clay ironstone nodules. Dark-reddish-brown-weathering clay ironstone occurs as scattered nodules or in thin nodular beds. Spheroidal pyrite(?) concretions, mostly weathered to iron oxides, are sparse.

The total thickness of the quartzite unit is estimated to be about 400 feet. No complete uncomplicated section of this unit was found east of the Okpilak River. West of the river, Bunnell (1959, p. 43) reported a minimum thickness of 500 feet and a possible maximum of 800 feet.

STRATIGRAPHIC RELATIONSHIPS AND DEPOSITIONAL CHARACTER

In the Romanzof Mountains, the Echooka Member of the Sadlerochit Formation overlies Wahoo and Alapah Limestones of the Lisburne Group with disconformity to at least slight angular unconformity. The Ivashak Member is overlain by the Shublik Formation with possible disconformity. No evidences of unconformity within the Sadlerochit Formation have been recognized in this area.

The base of the Sadlerochit is exposed in a few cliffs on the east valley wall of the Okpilak River, 2 miles south of Okpilak Lake. The contact is abrupt. Basal Sadlerochit beds are locally conglomeratic, contain chert possibly derived from the Lisburne Group, and overlie more than one horizon in the Wahoo Limestone. The Sadlerochit beds overlie the Lisburne with apparent conformity or with slight discordance not exceeding 5°, although apparent discordance of as much as 20° was seen in one exposure of the contact in this vicinity.

If the base of the Sadlerochit is interpreted to represent an erosional unconformity marked by beveling of low-dipping strata, the local absence of the normally underlying Wahoo Limestone indicates pre-Sadlerochit erosional relief of more than 200 feet in the area. The presence of a Late Mississippian-Pennsylvanian regional unconformity in much of the Brooks Range has been verified elsewhere (Brosgé and others, 1962, p. 2195). In the Romanzof Mountains area, the hiatus was not accompanied by severe diastrophism, although some warping probably occurred.

Contacts between members of the Sadlerochit Formation are not well exposed owing to the shaly character of the contact rocks. Relationships between the Echooka and Ivishak Members appear to be gradational, and the contact is placed between resistant and poorly resistant rocks. The shale and quartzite units are almost certainly gradational or intertonguing, with thin quartzite beds appearing in the upper 100 feet or so of the shale unit and culminating in thick massive quartzite beds.

The contact between beds mapped as Sadlerochit Formation and the overlying Shublik Formation is poorly exposed high on the valley wall of the Okpilak River, three-fourths mile east of Okpilak Lake. The highest Sadlerochit beds are slates, in part iron stained. These are overlain with apparent conformity of basal phosphate-pebble sandstone of the Shublik, but detailed contact relationships are masked by rubble.

Rocks of the Sadlerochit Formation in the Romanzof Mountains are believed to be entirely marine. The Echooka Member is interpreted to represent deposition in a shallow shelf-type environment during a relatively rapid but fluctuating marine transgression. Source areas for the formation were probably to the north, as shown by isopach and lithofacies maps of Detterman (1970a). This had been previously inferred from the apparent northward thinning of the formation and coarser detrital rocks in the Sadlerochit Mountains (Leffingwell, 1919, p. 113; Whittington and Sable, 1948, p. 8), as well as the shaly character and presence of limestone in the lower part of the Sadlerochit southeast and southwest of the Romanzof Mountains (Brosgé and others, 1962, p. 2193–2194). Pennsylvanian, Mississippian, and older metasedimentary rocks probably contributed to the sediments. The shale unit was deposited below wave base, and locally abundant pyrite and organic matter may represent deposition in a euxinic environment. The quartzite unit was deposited under shallow shelf conditions, at least in part above wave base, and represents a progressively shallower and more nearshore environment upward in the section. Detterman (1970a) interpreted the Ivishak Member as a deltaic deposit in which two delta systems may be represented, one in the western Romanzof Mountains and one farther west.

AGE AND CORRELATION

Invertebrate faunas found in the Sadlerochit Formation consist of abundant but poorly preserved spiriferoid, productid, and orthotetid brachiopods in the lower unit of the Echooka Member, one possible pelecypod impression in slate of the shale unit of the Ivishak Member, and scattered pelecypod molds and one partial ammonite case in quartzites and limy sandstones of the quartzite unit.

Fossils from the Echooka Member of the Sadlerochit were identified by J. T. Dutro, Jr., of the U.S. Geological Survey, and are shown in table 5. Dutro (written commun., 1960) stated that "The collections * * * contained elements of the Permian brachiopod fauna found in many places in northeastern Alaska. The age is late Early Permian or early Late Permian."

TABLE 5.—*Fossils from the Echooka Member of the Sadlerochit Formation, Romanzof Mountains*
[Identifications by J. T. Dutro, Jr.]

General locality (pl. 1)	Field No.	Stratigraphic position above base (ft)	Identification
Okpirourak Creek......	57ASa119	2–10	*Spiriferella?* sp.
Okpilak River...........	58ASa24	34–44	echinodermal debris, indet., orthotetid brachiopod, indet. *Anidanthus?* sp. *Spiriferella?* sp.
Tributary of Old Man Creek.......	58ASa138	0–50	*Spiriferella?* sp.
Do........................	58ASa159	(?) (from creek gravels)	*Anidanthus?* sp., *Waagenoconcha?* sp.
Between Okpilak and Hulahula Rivers.	58ASa596	(?)	*Spiriferella* sp.

The fossils listed in table 5 are similar to those reported by Leffingwell (1919, p. 114) and other workers in northeastern Alaska. Fossils from the lower part of the formation had previously been identified by Girty (Leffingwell, 1919, p. 114–115), who referred them to the Pennsylvanian (Gschelian). Later, according to Smith (1939, p. 32), " * * * Girty is now convinced that it (the early Sadlerochit fauna) is more properly to be regarded as belonging to the Permian." J. T. Dutro, Jr. (oral commun., 1956), after examination of many Sadlerochit Formation collections, stated that fossils in the lower part of the Sadlerochit are definitely Permian.

An ammonite (field No. 58ASa160, USGS Mes. loc. M1028) was collected on the divide between Old Man Creek and Hulahula River drainages about 400 feet above the base of the quartzite unit of the Ivishak Member and identified by N. J. Silberling of the U.S. Geological Survey as *?Ophiceras (Lytophiceras)* cf. *commune* Spath. Silberling (written commun., 1960) noted:

> Age: Early Triassic, if the choice is between this and an older age. Because this specimen is represented only by the body chamber, the identification and age assignment must be qualified. If the rocks from which it was collected are no younger than the Early Triassic, the identification is probably correct because this species has previously been reported from the Lower Triassic part of the Sadlerochit Formation. A Permian age is ruled out. However, this body chamber is similar to those of some younger Early Triassic and Middle Triassic ammonites, and a younger Triassic age cannot be precluded.

N. J. Silberling (written commun., 1965) later stated that "The ammonite fragment questionably referred to *Ophiceras* * * * might equally well be referred to the genus *Arctoceras* which is a characteristic member of * * * the mid Early Triassic fauna in Arctic Canada."

Pelecypods and ammonites of early and middle Early Triassic (Scythian) age have been collected from the Ivishak Member in other areas (Keller and others, 1961; Detterman, 1970a).

SHUBLIK FORMATION

NAME AND DEFINITION

First defined by Leffingwell (1919, p. 116–118), the Shublik Formation (Middle and Upper Triassic) is a distinctive unit in northeastern Alaska. Its equivalents in northwestern Alaska, though in part lithologically different, contain a similar fauna (Smith and Mertie, 1930, p. 185–194; Payne, 1952).

DISTRIBUTION AND OUTCROP

Exposures of the Shublik Formation, although of small areal extent, are widespread along the northern front of the Brooks Range (George Gryc, in Payne and others, 1952, sheet 3). In the Romanzof Mountains the formation crops out in a relatively narrow belt north of Sadlerochit Formation exposures, occurs in a few places as erosional remnants, or is sharply infolded with Sadlerochit rocks.

Good outcrops of the Shublik Formation are scarce because of its poorly resistant nature. One good exposure of part of the formation lies in a cutbank of a small stream along the east wall of the Okpilak River valley, 1 mile northeast of Okpilak Lake (measured section 10). Elsewhere, except for a few small cutbanks and steep hillsides, the formation can be traced only by recognition of rock types in frost heavings and rubble.

Weathered outcrops of most Shublik rocks have a characteristic bluish-white "phosphatic" efflorescence on otherwise black sooty-appearing exposures. The basal sandstone, however, commonly weathers pale brown and is slightly iron stained, similar to parts of the Sadlerochit Formation. On aerial photographs, the formation is not distinctive in appearance, but occupies belts of low relief.

LITHOLOGIC CHARACTER AND THICKNESS

The Shublik Formation is dominantly dark-gray to black limestone and limy shale, in large part phosphatic and fossiliferous. A dark sandstone and siltstone bed forms a persistent marker zone at the base of the formation. On this basis Leffingwell divided the formation into an upper limestone member and a lower sandstone member in the Canning River region.

In the Romanzof Mountains, the lower sandstone member, about 40–70 feet thick, is medium to dark gray, weathers pale to moderate yellowish brown, is fine to medium grained, and ranges from calcareous and well indurated to quartzitic. Beds are 1–2 feet thick, evenly bedded, and weather to irregular blocky fragments. Black, irregular, phosphatic, pebbly nodules as much as 2 inches in diameter make up perhaps 10–20 percent of the member. One thin section of phosphatic siltstone in the lower member of the Shublik Formation indicates about 30 percent probable collophane as amorphous grains, ooliths, and quartz-grain coatings in phosphatic silty matrix. Scattered quartz grains and mica flakes are also present.

The limestone member consists of dark-gray to black, argillaceous to sandy limestone interbedded with black, sooty, calcareous shale and fissile black limestone. Sandy limestone beds are blocky to platy, average less than 1 foot in thickness but are as much as 4 feet thick, and sets of beds are as much as 20 feet thick. Shale and fissile limestone occur in sets of beds as much as 30 feet thick. Blocky and platy limestone is dominant in the lower half of the limestone member. Shale and fissile limestone increase in abundance upward and constitute about 70 percent of the upper half of the member. Scattered spherical and ovoid limonite nodules, probably after pyrite, and clay ironstone nodules are rather sparse. A dark-yellowish-orange-weathering laminated silty limestone is present in rubble at or near the top of the Shublik in some exposures. Much of the limestone and shale is phosphatic, and the Shublik may be a potential source of rock phosphate.

The total thickness of the Shublik Formation may be as much as 700 feet on the east side of the Okpilak River. About 660 feet of this section is ascribed to the limestone member. Bunnell (1959, p. 46, 48) indicated about 70 feet for the sandstone member and about 550 feet for the limestone member 3½ miles west-southwest of this section.

STRATIGRAPHIC RELATIONSHIPS AND DEPOSITIONAL CHARACTER

Neither the top nor the bottom of the Shublik Formation is well exposed in the area. The relatively abrupt change in rock character between the sandstone member and the Sadlerochit Formation, despite their apparent structural conformity, implies a corresponding change in sedimentary conditions. Lithologies of the limestone member resemble those of the Phosphoria Formation of the Western United States. The quartzite beds mapped in the overlying Jurassic Kingak Shale also represent a rather abrupt change back to dominantly detrital deposition, but the beds also contain some Shublik-like features. The Shublik Formation is widespread in northern Alaska and reflects relatively constant conditions of marine sedimentation, but at present too little is known about its broader relationships to place this area in a regional depositional framework. The rocks in the Romanzof Mountains are lithologically almost identical to those reported by other workers in northeastern Alaska, although the basal sandstone is not present in all areas. Farther east, Upper Triassic rocks similar to those in the Romanzof Mountains occur in the British Mountains (Maddren, 1912). To the west, a different facies of Shublik Formation consists mostly of shale, light-hued sublithographic limestone, cherty limestone, and bedded chert. Most sections of Shublik Formation do not exceed a few hundred feet in thickness.

AGE AND CORRELATION

The Shublik is locally very fossiliferous. Fossils are abundant near the middle and at the top of the limestone member and they are scattered throughout the upper half of the formation, but none were found in the basal sandstone member. They consist of monotid-type pelecypods, rhynconellid and terebratuloid brachiopods, belemnite and nautiloid fragments, and gastropods. Shell material is phosphatic or calcareous. In several localities *Monotis* cf. *M. subcircularis* Gabb and *Halobia* cf. *H. cordillerana* Smith were identified by me, and three collections were identified by N. J. Silberling, U.S. Geological Survey (table 6).

TABLE 6.—*Fossils from the Shublik Formation, Romanzof Mountains*
[Identifications by N. J. Silberling]

General locality (pl. 1)	Field No.	Stratigraphic position	Identification
Mountain front, Okpirourak River.	57ASa13	In upper one-third.	*Halobia* sp., indet.
2½ miles west of Okpilak Lake.	58ASa83	About 450 ft above base.	*Steinmannites*? sp. *Paranautilus sp.* *Monotis subcircularis*?, Undetermined low-spired gastropods. Belemnites
East valley wall, Okpilak River.	58ASa126	In upper one-third.	*Halobia* sp., indet. *Oxytoma* sp. *Monotis*?—immature Belemnite

Silberling (written commun., 1960) indicated a Late Triassic age for the first collection shown on table 6, and a late Late Triassic (middle or late Norian) for the others. Silberling (written commun., 1965) reexamined collections from northeastern Alaska, including one collection of Karnian age from the Romanzof Mountains, and has concluded that the Shublik in northeastern Alaska ranges in age from Ladinian (late Middle Triassic) through Norian (Late Triassic) (Silberling, 1970).

Although the contact between the Shublik Formation and Kingak Shale is placed at the base of a resistant quartzitic siltstone in the present report, in other reports similar siltstone or sandstone beds are included in the Shublik.

JURASSIC SYSTEM

KINGAK SHALE

NAME AND DEFINITION

Named by Leffingwell (1919, p. 119–120) after Kingak Cliff at the southeast end of the Sadlerochit Mountains, the Kingak Shale was defined to consist of about 4,000 feet of concretion-bearing black shale. According to Leffingwell, the Kingak Shale overlies the Shublik Formation with apparent conformity and probably directly underlies the Ignek Formation. Subsequent to Leffingwell's work, the outcrop belts of Kingak have been extended both east and west of the type locality (Gryc and Mangus, 1947; Mangus, 1953; Keller and others, 1961). Many of the exposures reported by Leffingwell have been reexamined, and megafossils and microfossils from the formation have been described (Imlay, 1955; Tappan, 1955).

The Kingak Shale in this area is divided into a basal siltstone member and a thick overlying black shale member, as reported earlier by Sable (1959, p. 70) and Bunnell (1959, p. 50). Some uncertainty exists as to whether the siltstone member should be included in the Kingak. Outside the area, beds of similar lithology and stratigraphic position have been found to contain fossils identified as Early Jurassic and Late Triassic at separate localities (Whittington and Sable, 1948; Detterman, 1970a). It has been suggested that some of these beds should be included in the Shublik Formation or that they deserve recognition as a separate nomenclatural unit (Tailleur and Tourtelot, 1971; Detterman, 1970a). Because questions of age and equivalency of the various occurrences of beds of this kind in northeastern Alaska are yet unresolved (Reiser, 1970; Detterman, 1970; Brosgé and Tailleur, 1970), and because no fossils have been identified from this unit in the western Romanzof Mountains, the siltstone unit is herein provisionally retained in the Kingak Shale.

DISTRIBUTION AND OUTCROP

The Kingak Shale is poorly exposed and crops out sporadically along the north front of the Romanzof Mountains. Between the Okpilak and Jago Rivers a linear belt of exposures strikes east-northeast. Between the Okpilak and Hulahula Rivers the belt strikes generally northwest; in addition, one erosional remnant of the Kingak lies south of these exposures and makes up a prominent butte 2 miles west of Okpilak Lake (fig. 5).

Basal quartzitic siltstones and sandstones of the formation form ridges as much as 300 feet high. North of these ridges the poorly resistant shale beds of the Kingak crop our in a few stream cutbanks and low hills, but elsewhere they are covered by tundra or glacial deposits.

LITHOLOGIC CHARACTER AND THICKNESS

The siltstone member consists of quartzitic sandy siltstone to fine-grained sandstone, limy sandstone, and lesser amounts of dark-gray shale. Siltstone and sandstone are medium gray to medium dark gray and olive gray, weather light brown, are evenly bedded, apparently ungraded, massive, and resistant, with beds averaging about 4 feet in thickness. Limy sandstone, which occurs mostly in the upper part of the member, is medium dark gray, fine grained, and weathers distinctive pale yellowish brown and light brown. Subround to irregular dark-gray phosphatic pebbles or nodules in siltstone are as much as 2½ inches in diameter and are scattered throughout the member; argillaceous pellets are scattered along bedding planes. A few calcareous shell fragments (pelecypods?) are present in the limy sandstone.

Although the maximum thickness of the siltstone member along the Okpilak River is about 75 feet, incomplete exposures of this unit along Okpirourak Creek drainages and west of the Okpilak River are at least 150 feet thick. Some individual quartzitic siltstone beds reach a thickness of 20 feet.

The Kingak consists mostly of dark-gray to black shale of the black shale member, as inferred from scattered rubble and frost heavings north of basal Kingak beds, although little of this rock type is exposed near the Romanzof Mountains. A few cutbank exposures of the black shale member were examined along tributaries of the Okpirourak River. Here the rocks consist of about 85 percent dark-gray to grayish-black, fissile, silty shale with interbedded dark-gray, platy to blocky siltstone beds less than 2 inches thick. The shale is in part pyritic, and both shale and siltstone weather dark yellowish orange and commonly exhibit a whitish to moderate-yellow efflorescence. A few clay ironstone lenses and nodules which weather dark reddish brown were seen in rubble of this member. The thickness of the black shale member along the Romanzof Mountain front is unknown but probably exceeds 1,000 feet.

STRATIGRAPHIC RELATIONSHIPS, AGE AND CORRELATION

Poor exposures and lack of identifiable fossil remains permit only general statements regarding age and relationships of Kingak beds within the area. The abrupt change from the phosphatic organic shale and limestone of the Shublik Formation to the variable thicknesses of the siltstone member in the basal part of the Kingak may indicate an eorsional or nondepositional break before deposition of the siltstone. Basal Kingak deposition was sluggish, and sediments accumulated below wave base; bedding features indicative of wave or current activity were not seen. The shales are marine and were deposited, perhaps, in a deep restricted basin or in a subsiding basin adjacent to a slowly riding source area of relatively low relief. It has been suggested that source areas for these rocks may have lain to the south. An interpretation by Keller, Morris, and Detterman (1961, p. 191) is that the upper part of the Kingak Shale represents a northerly offshore equivalent of graywacke-type sediments. They (p. 193) stated that the Kingak Shale may be characterized by overlap relationships or unconformities, previously suggested by Imlay (1955) on the basis of faunal evidence. Brosgé and Tailleur (1970), however, see little evidence for a southern source area until Cretaceous time. The siltstone member of the Kingak might be interpreted to represent initial clastic influx from a slowly rising source followed by downwarping and subsequent deposition of the thick black shale member. Thick Jurassic shales and sandstones in the Richardson Mountains of the Yukon Territory are interpreted by Martin (1959, p. 2428, 2451) to reflect a north-trending Jurassic basin in that area. The extensive outcrop areas of thick Kingak Shale to the west (Keller and others, 1961, p. 191), however, suggest that the basin had a more westerly trend, or that more than one basinal component existed in northeastern Alaska and northwestern Canada.

First classified as Lower Jurasic (Leffingwell, 1919, p. 119–120), the Kingak Shale and probable equivalents were later placed in the Middle and provisionally in the Lower Jurassic by Smith (1939, p. 46). Fossils from the Kingak Shale elsewhere in northeastern Alaska have since been reported by Imlay (1955) to represent parts of the Pliensbachian and Toarcian Stages of the Lower Jurassic, the

Bajocian and Callovian Stages of the Middle Jurassic, and the Oxfordian and Kimmeridgian Stages of the Upper Jurassic. Several breaks during Middle and Late Jurassic time are suggested by Imlay.

The few shell fragments found in the siltstone member of the Kingak Shale are too frammentary to yield age information. As stated previously, other similar siltstones and sandstones in northeastern Alaska have yielded fossils identified as Late Triassic forms. Further study is required to determine whether all these units are correlative or are nearly contemporaneous but discrete rock bodies.

CRETACEOUS SYSTEM

IGNEK(?) FORMATION

Interbedded sandstone, shale, and coaly beds tentatively correlated with the Ignek Formation are poorly exposed in low whaleback ridges along Okpirourak Creek and along the Jago River. Other exposures in the foothills north of the Romanzof Mountains, delineated from aerial photograph study, are mapped as Ignek(?) (pl. 1). The Ignek Formation, first described by Leffingwell (1919, p. 120–125), contains nonmarine lithologies and, in some parts, a marine or transitional fossil fauna. Although Leffingwell considered the Ignek to be Jurassic(?) in age, more recent studies of this formation and its traceable equivalents in areas northwest of the Romanzof Mountains place the Ignek in the Cretaceous (Imlay, 1961; Keller and others, 1961; Reiser, 1970). The strata in the area here described are unfossiliferous except for carbonaceous fragments; neither the thickness of the sequence nor its relationships to other rocks are known except that the Ignek(?) rocks are unconformably overlain by Quaternary glacial and glaciofluvial deposits. These rocks, however, are different from the thick marine graywacke-shale "flysch" type units of Early Cretaceous age in south-central and western areas of northern Alaska. The Ignek(?) strata were deposited in nonmarine, transitional, and shallow-water marine shelf-type environments.

The exposures on Okpirourak Creek, 3 miles northwest of Jago Lake, consist of at least several hundred feet of interbedded sandstone and shale. The sandstone, which makes up about 50 percent of the exposures, is medium dark gray to medium gray, weathers grayish red and brownish gray, in part with "gun-metal blue" stain and iron stain. It is very fine to medium grained, weathers platy to flaggy, and contains scattered carbonized wood fragments. Small ripple and current marks occur on some sandstone surfaces. Clay and silty shale is dark gray to black, hackly to fissile, and contains scattered clay ironstone nodules. Examination of one thin section of sandstone from these exposures indicates the rock to be a lithic graywacke. Poorly sorted as to type and size, subangular to subround grains constitute 75 percent of the section and include strained quartz, argillite or slate, and chert with lesser amounts of fresh plagioclase (oligoclase(?)), calcite, and quartzose sandstone. The matrix is dominantly a mixture of clay and carbonaceous material and it contains some quartz, limonite, and hematite.

Carbonaceous sandstone, thin coal beds, and black carbonaceous shale crop out on a ridge west of the Jago River, 9 miles north of Jago Lake. These exposures lie along the same general strike as the Okpirourak Creek exposures and are considered to be roughly equivalent to them.

QUATERNARY SYSTEM

GLACIATION

Pleistocene and Holocene glaciations have resulted in striking depositional and erosional features in and north of the Romanzof Mountains. The mountains have been strongly sculptured, mostly by north-flowing glaciers which originated in and south of the mapped area and which represent nearly all of the existing glaciers in northern Alaska. Most of the larger glaciers, remnants of earlier extensive glaciations, are 3–5.5 miles long and are compound, but several are relatively simple and suited to glaciological studies such as those carried out during the 1957–58 International Geophysical Year on McCall Glacier (Mason 1959; Slater, 1959). Besides the classic erosional land forms produced by mountain glaciation, ice-contact and glaciofluvial deposits are found along most of the tributary streams, the major river valleys, and in interstream areas beyond the north limits of the mapped area (pl. 1). Good evidence for older piedmont-type glaciers and successively younger shrinking valley glaciation is indicated mainly from position and degree of modification (by erosion, frost action, and weathering) of moraines and outwash, and the degree of vegetation encroachment on them. Some crosscutting relationships of valley glacier features are also present where tributary streams enter major valleys. Other than the glacial features, Holocene materials consist of modern stream deposits which are largely reworked glacial material, large alluvial fans and talus cones along the major river valleys, mixed colluvium along steep slopes, thin layers of windblown silt on river flats, and small ephemeral aufeis fields, ice domes, and ice wedges in a few localities. Permafrost of unknown depth is probably present throughout the area.

PERTINENT BROOKS RANGE INVESTIGATIONS

Features of multiple glaciation on the north slope of the Brooks Range have been studied in several areas, and the glacial sequences recognized in different parts of the range have been tentatively correlated. Provincial nomenclatures for Pleistocene and Holocene piedmont and valley glaciations in the central and eastern Brooks Range are reviewed as follows. In the central Brooks Range, 120 miles west-southwest of the Romanzof Mountains, Detterman (1953, p. 11–12) named four glaciations, from oldest to youngest: the Anaktuvuk River, Sagavanirktok River, Itkillik, and Echooka River. Detterman, Bowsher, and

Dutro (1958) discussed these in greater detail, extended the names farther west, and named two younger glaciations, the Alapah Mountain and Fan Mountain. All except Fan Mountain Glaciation were considered by them to be of Pleistocene age, and they suggested that Anaktuvuk River and Sagavanirktok River Glaciations may represent a single advance. Porter (1962, 1963, 1964, 1966) made detailed studies of post-Sagavanirktok River glaciations in the Anaktuvuk Pass area, north-central Brooks Range. Although he retained most of the earlier central Brooks Range nomenclature, he extended Itkillik Glaciation to include Detterman's Itkillik plus the Echooka River. The name Echooka River Glaciation was abandoned in favor of Itkillik by Detterman (1970b, p. 131).

In the eastern Brooks Range, Leffingwell (1919, p. 133–149, 156–158) implied that a single Pleistocene ice advance had extended 10–12 miles north of the mountain front along the Okpilak and Hulahula Rivers, but cited evidence that glaciers had extended farther north in other areas. In the Mount Chamberlin area, Franklin Mountains, about 10–15 miles west of the Romanzof Mountains, Holmes (1959) and Holmes and Lewis (1961) named five successive glaciations the Weller, Chamberlin, Schrader, Peters, and Katak, which they tentatively correlated with the central Brooks Range sequence. Holmes and Lewis (1965) later significantly modified some of their earlier correlation attempts. Reed (1968) did further work in and adjoining this area and concluded that an additional ice advance between Peters and Katak corresponded to Alapah Mountain Glaciation. Brooks Range 1953–68 glacial nomenclature and age assignments were tabulated by Reed (1968, p. 62–63).

Farther east, in the Romanzof Mountains, Kunkle (1958), Keeler (1959), and Sable (1961, 1965), although not in complete agreement, have outlined a sequence of multiple glaciation similar to that of other Brooks Range workers. Kunkle recognized six ice advances in the Jago and Okpilak River valleys and correlated them with the central Brooks Range sequence of Detterman, Bowsher, and Dutro (1958). Keeler cited evidence for five advances along McCall Glacier and McCall Creek Valley and also compared them with the central Brooks Range glaciations. Sable (1965) discussed evidence for five advances. Sable (1961) also recognized a very recent stage of retreat for the Okpilak Glacier in the Romanzof Mountains.

The Quaternary geology of the western Romanzof Mountains shown on plate 1 and discussed here results from numerous but scattered observations made by me, Kunkle (1958), and Bunnell (1959), augmented by my examination of aerial and field photographs. Map units and conclusions of Kunkle (1958) and Keeler (1959) are incorporated in modified form in the present report.

I recognize five assemblages of glacial depositional and erosional features in the area, which, in morphology, position, degree of modification, and, in part, degree of vegetation encroachment, appear to be distinct enough to relate them to separate glacial advances. They reflect successively shrinking glaciers. Uncertainties exist, however, in the precise delineation and correlation of the assemblages from place to place and in the recognition of their boundaries. Along the major river valleys and interstream areas north of the mountain front, sets of recessional moraines are present which in their degree of modification appear to grade northward into older recessional moraines, and crosscutting relationships, if present, are obscure. Within the mountains some crosscutting relationships may be seen where tributary glaciers have overridden older trunk glacier moraines, but detailed relationships of most tributary glacier deposits to main valley glacial features are still unknown. In addition, locations of glaciofluvial deposits relative to terminal moraines have been delineated in only a few places.

Correlation of glacial deposits in this area with those in other Brooks Range areas is uncertain. Morphologic features and their degree of modification perhaps cannot be directly compared because bedrock source areas are radically different. Granitic debris, much of it very coarse and resistant, comprises most of the western Romanzof Mountains deposits. In contrast, glacial deposits in other Brooks Range areas are composed of sedimentary and metasedimentary rocks. Romanzof Mountains deposits may appear to be fresher, and therefore younger, than deposits of synchronous advances elsewhere in the Brooks Range.

Deposits of the five advances are differentiated on plate 1; form lines also indicate the approximate outer limits of prominent moraines. Table 7 is intended primarily to show tentative correlations with the Mount Chamberlin and Lake Peters areas. Differences between these correlations and my earlier ones (Sable, 1965) result from reevaluation of data in the Romanzof Mountains in view of more recently published information by Holmes and Lewis (1965), Porter (1966), and Reed (1968). Central Brooks Range terminology is also included because Holmes and Lewis attempted provisional correlation with that region, and because Kunkle (1958) also used central Brooks Range terminology. Kunkle's usage, however, is shown relative only to that of the present paper.

FIRST ADVANCE

FEATURES

Deposits that occur at the northern limits of the area and at least 1 mile farther north are attributed to the oldest known advance, which may correlate with the Weller and (or) Chamberlin Glaciations (Holmes and Lewis, 1961). They include scattered erratics in tundra-covered lowland areas without observable morainal traces. Lakes and ponds are sparse and have been mostly filled, drainage is well integrated, and numerous well-drained areas with bedrock traces and outcrops indicate that the deposits are

TABLE 7.—*Tentative correlations of glacial advances in the Romanzof Mountains, Brooks Range, with glacial advances in other parts of the Brooks Range*

Romanzof Mountains (this report)	Jago River (Kunkle, 1958)	Lake Peters area (Reed, 1968)	Mount Chamberlin area (Holmes and Lewis 1965)	Anaktuvuk Pass (Porter, 1964)	Central Brooks Range (Detterman, Bowsher, and Dutro, 1958)
Fifth advance	Fan Mountain Glaciation	Katak Glaciation	Katak Glaciation	Fan Mountain Glaciation II Fan Mountain Glaciation I	Fan Mountain Glaciation
Fourth advance	Alapah Mountain Glaciation	Alapah Mountain Glaciation		Alapah Mountain Glaciation	Alapah Mountain Glaciation
Third advance	Echooka River Glaciation	Peters Glaciation Schrader Glaciation	Peters Glaciation Schrader Glaciation	Itkillik Glaciation (four named stades)	Echooka River Glaciation Itkillik Glaciation
Second advance	Itkillik Glaciation Sagavanirktok River Glaciation	Chamberlin Glaciation	Chamberlin and Weller Glaciations	Not recognized in area	Sagavanirktok River Glaciation
First advance	Anaktuvuk River Glaciation	Not exposed			? Anaktuvuk River Glaciation

probably thin. In some interstream areas, 2½ miles southwest of Jago Lake, highly weathered "rotten" granite erratics are attributed to this advance, as are fragments of quartzite, schist, chert, and phyllite. The northward extent of this glaciation is unknown, and its southernmost deposits north of the mountains are obscured by drift and outwash of the second advance.

Within the mountains along the Okpilak River valley, altitudes of the approximate upper limit of glaciation as inferred by the highest granite erratics in areas of bedrock are 3,500 feet west of Okpilak Lake 3,700 feet 1 mile southeast of the lake, and 3,800 feet 3½ miles southwest of it. Southward, erosional features in granite terrain include truncated spurs, the tops of which lie at 5,000–5,200 feet between Leffingwell and Arey Creeks, about 5,300 feet 4 miles south of Leffingwell Creek, and 6,100 feet 2 miles southwest of the main Okpilak River forks.

Along the Jago River, glacial erratics occur at altitudes of about 3,200 feet at the mountain front, although ice from the McCall Glacier reached about 3,850 feet at the pass between McCall Glacier and Jago Lake (Kunkle, 1958, p. 18; Keeler, 1959, p. 91). Along the south side of McCall Creek, a high bedrock bench sloping downstream from about 4,000 to 3,400 feet altitude is thinly veneered by boulders and tundra vegetation. I agree with Keeler (1959, p. 91) that the bench corresponds in altitude with the pass and with the highest morainal material along the Jago River and that it marks the approximate upper limit of glaciation in this vicinity. Southward along the Jago River valley, erratics occur as high as about 3,400 feet one-half mile south of McCall Creek and 3,500 feet 1 mile farther south. Tops of modified faceted spurs 7 and 10 miles south of McCall Creek are at 4,000- and 4,800-foot altitudes, respectively.

The First advance was obviously of piedmont type. South of the mountain front it was mostly restricted to the main valley along the Okpilak River, but on the Jago River it overrode the pass north of and the low area east of McCall Creek, and so the two small mountain masses flanking the Jago River valley stood as nunataks above the ice.

CORRELATION

Kunkle (1958) correlated this glaciation with the Anaktuvuk River Glaciation (Detterman, Bowsher, and Dutro, 1958). In the McCall Creek valley, Keeler (1959) correlated it with either the Anaktuvuk River or Sagavanirktok River Glaciation.

SECOND ADVANCE

FEATURES

The Second advance is represented by considerably modified end moraines and outwash aprons 10 miles and about 15 miles north of the mountains along the Jago and Okpilak Rivers, respectively. Morainal ridges generally have smooth surfaces with scattered granite and subordinate quartzite boulders and boulder patches. Surface material has been considerably reworked by frost action; constituents are similar to those in deposits of the First advance, but granite erratics are more numerous. Moraines and outwash are covered by tundra vegetation except along their crests where vegetation is patchy and conspicuous patterned ground features are common.

Several distinct moraines, interpreted as recessional, are present on both the Okpilak and Jago Rivers (pl. 1), and

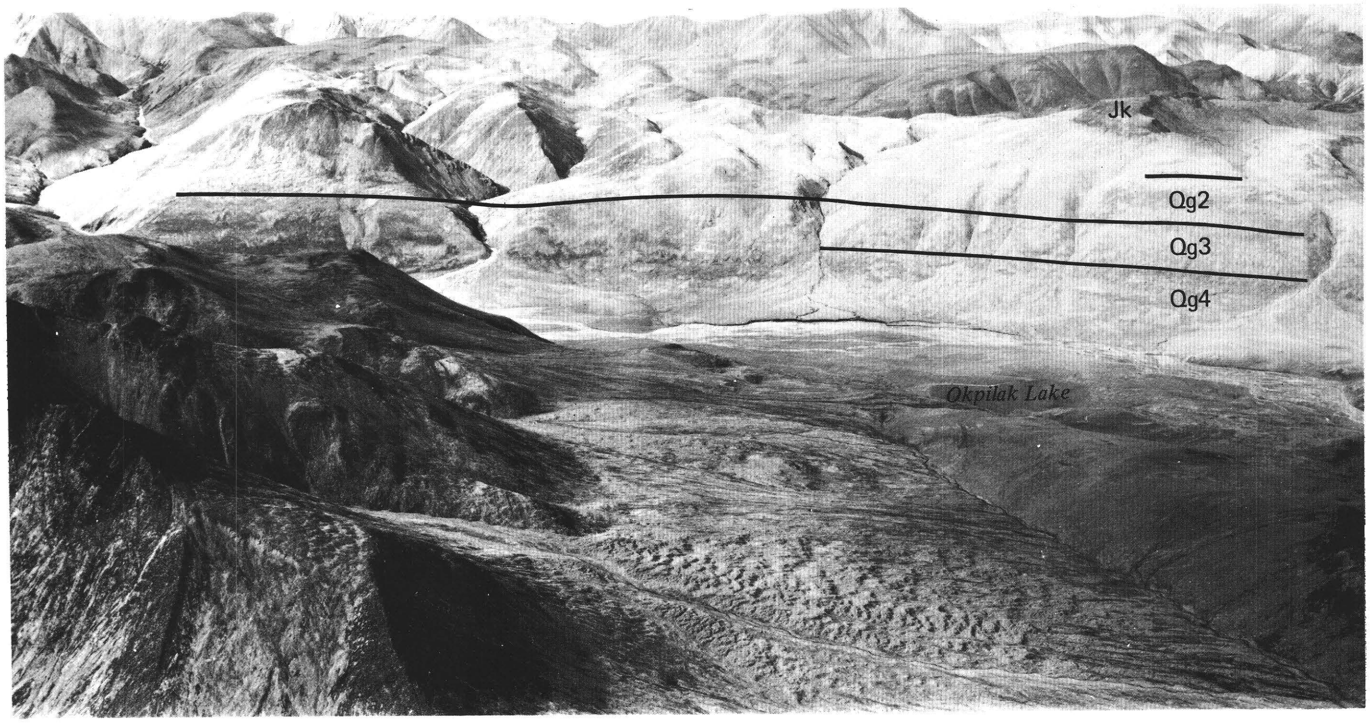


FIGURE 5.—Oblique photograph of Okpilak River valley, looking west. Lateral moraines ascribed to Second (Qg2), Third (Qg3), and Fourth (Qg4) advances on west valley wall. Butte in right background capped by quartzite of Kingak Shale (Jk). Tight folds of quartzite unit, Ivishak Member, Sadlerochit Formation in left foreground. Photograph by U.S. Navy.

several kettle lakes are present near the Jago River. Moraines are partly cut through by the headwaters of the integrated drainage pattern found farther north, although some arcuate stream patterns still parallel the morainal traces.

Within the mountains the upper limit of this advance is difficult to determine. Concentrations of lichen-covered bouldery till representing modified lateral moraines occur as high as 3,300 feet west and southwest of Okpilak Lake (fig. 5) and more than 4,000 feet 6 miles farther south. Along the Jago River, rough upper limits of similar boulder concentrations occur at altitudes of about 3,300–3,600 feet along McCall Creek (Keeler, 1959, p. 91) and about 3,000–3,500 feet 1–4 miles south of McCall Creek.

Although major tongues of this advance probably coalesced to some extent in interstream areas 5–6 miles north of the mountain front, it is doubtful that a continuous piedmont cover was present. Outwash from the trunk glaciers probably coalesced and thus determined the course of Okpirourak Creek north of the mountains. If ice did flow through the pass north of McCall Glacier (Kunkle, 1958, p. 20–21), it was thin. Likewise, the low area east of McCall Creek, where patchy bouldery drift occurs at 2,900 to 3,000 feet, was probably only slightly overridden.

CORRELATION

Kunkle (1958) considered deposits of this advance 6–9 miles north of Jago Lake to be correlative with the Sagavanirktok River Glaciation. His northern limits agree generally with those of the Second advance, but the Second advance also includes deposits which Kunkle placed in the younger Itkillik Glaciation along the Jago River. Along the Okpilak River, the Second advance agrees approximately with Kunkle's Sagavanirktok River Glaciation. I recognized only subtle differences between the northern exposures of Kunkle's Itkillik deposits and southern exposures of his Sagavanirktok River deposits; the abundance of erratics increases and morainal ridges are more distinct and possess higher relief inward but do not appear to contrast sharply with those farther north.

THIRD ADVANCE

FEATURES

The Third advance was entirely restricted to the major river valleys and mountain tributaries; trunk glaciers reached to 4 and 6 miles north of the mountain front along the Jago and Okpilak Rivers. Prominent lateral moraines and kame terraces, kettle lakes with bouldery bottoms, knobby topography, and coarseness of till are characteristic along the Jago River (Kunkle, 1958, p. 26–29). Frost pattern features appear to be less mature than those on deposits of the Second advance. Lowland areas contain thin tundra vegetation, but knobs and ridges are relatively bare. Along the Okpilak River, similar topography is present 4–7 miles north of Okpilak Lake, where several moraines converge on the river; the northernmost moraine corresponds to a conspicuous bench along the west valley wall, similar to one on the east valley wall of the Jago River. Arcuate drainage around end and recessional moraine limits is pronounced. In this respect, topographic features of this advance and the southernmost ones of the Second advance resemble the Schrader Glaciation of the Mount Chamberlin area (Holmes and Lewis, 1961, p. 857–859 and fig. 10).

Evidence for limits of this glaciation within the mountains has been largely masked by mixed morainal material that resulted from mass wasting and by lateral moraines from tributary glaciers that have entered the river valleys at altitudes higher than the trunk glacier. Lateral moraines at the mountain front along the Okpilak River are at about 2,700-foot altitude. Trimlines at 3,000 3,500, and 4,000 feet, 4, 7, and 11 miles respectively south of Okpilak Lake approximately correspond to the apexes of the highest alluvial and talus fans in those areas. Along the Jago River, tops of lateral moraines as traced southward from the end moraine are at altitudes of about 2,200 feet at the mountain front and perhaps 3,000 feet 11 miles south. Moraine surfaces within the mountains consist mainly of granite boulders, are heavily encrusted by rock lichens, and have a thin, patchy tundra cover; fines have been largely washed from them.

CORRELATION

The Third advance along the Jago River corresponds with the Echooka River Glaciation (Kunkle, 1958). The northern limit of the Third advance, along the Okpilak River, corresponds approximately with the northern limits of deposits ascribed to the Itkillik Glaciation by Kunkle (1958, map on p. 38, but not so noted by him in text, p. 24, in which he includes older deposits which I place in the Second advance). Deposits ascribed to Echooka River Glaciation by Kunkle (p. 29–30) occupy the same position, relative to the mountain front, on both rivers, but the northern limits along the Okpilak River were not clear to him because he recognized no end moraine.

The difference in position between the limits of the Third advance along the Okpilak and Jago Rivers (pl. 1) is based partly on the assumption that the glacier regimen during this and succeeding advances was similar to the present regimen, although larger in scale. At present, the ice volume of glaciers drained by the Okpilak River is greater than the volume of those drained by the Jago River, although the Jago has the larger drainage area. Furthermore, many of the Jago River glaciers are far south of this report area, and it is doubtful that they reached the northern part of the Jago River valley during Third advance time. In the mapped area, the Okpilak River valley and the Jago River valley are of similar dimensions. It follows then, that the Okpilak River valley had a larger volume of ice, which resulted in more northerly positions of equivalent advances and recessions than in the Jago River valley. This interpretation, combined with the gross morphologic similarity of the deposits, is believed to indicate their equivalency.

FOURTH ADVANCE

FEATURES

Deposits of the Fourth advance indicate that a thin trunk glacier extended beyond Okpilak Lake in the Okpilak River valley; a similar glacier in the Jago River valley did not reach the mountain front. The extent of this glaciation along the Okpilak River valley is shown by single-crested, well-developed lateral moraines 200–300 feet above the river 8–13 miles south of Okpilak Lake (fig. 6). Tributary moraines attributed to this advance extend from Arey Glacier and Leffingwell Glacier into the valley at altitudes slightly higher than and parallel to the main lateral moraines. These can be traced northward intermittently along the west valley wall as far as 1½ miles north of Okpilak Lake, and they appear to correlate with moraines which close on the river about 4 miles north of Okpilak Lake.

Glacial deposits along the Hubley Creek tributary of the Jago River are keys to understanding the Fourth advance.

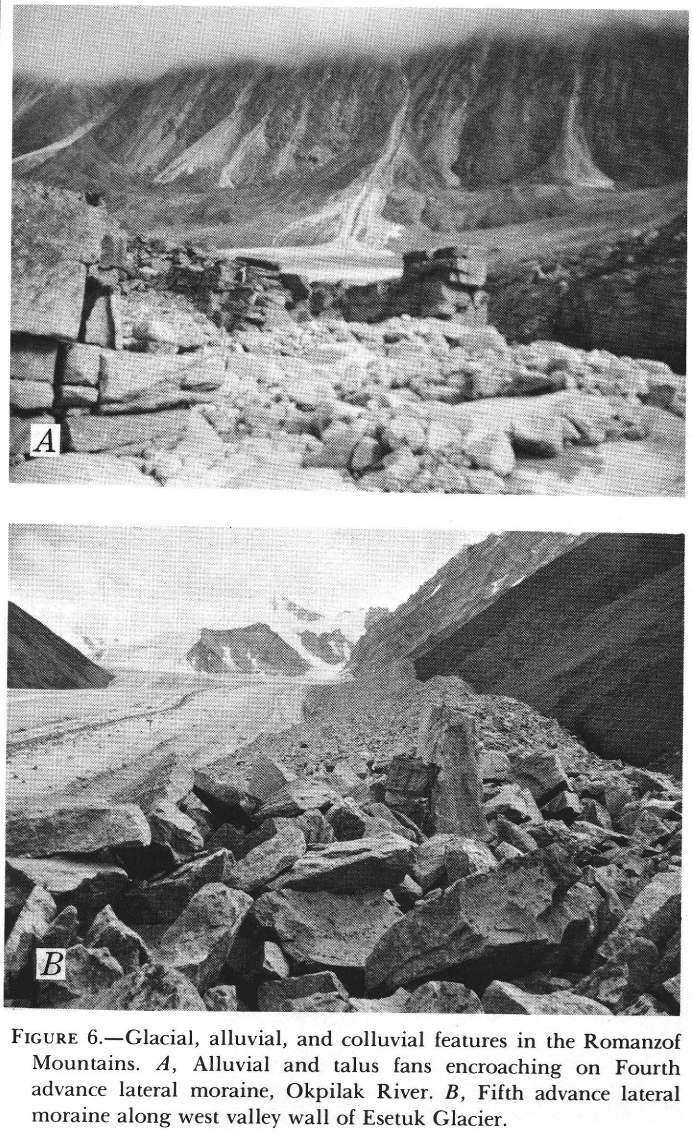


FIGURE 6.—Glacial, alluvial, and colluvial features in the Romanzof Mountains. *A*, Alluvial and talus fans encroaching on Fourth advance lateral moraine, Okpilak River. *B*, Fifth advance lateral moraine along west valley wall of Esetuk Glacier.

An end moraine ascribed to Fourth advance extends over older glacial deposits at the mouth of the creek (pl. 1). This moraine is correlated with the end moraine 1½ miles upstream from McCall Creek mouth on the basis of morphology and position in respect to relative size of the parent glaciers. No moraines of this advance have been recognized in the Jago River valley north of Hubley Creek, but 3–9 miles south of the creek well-preserved lateral moraines occur about 250 feet above the river. They are considered to be Fourth advance deposits originating far upstream.

Fourth advance morainal material within the mountains is poorly sorted, shows little evidence of weathering, and supports a thin partial cover of rock lichens and tundra plants. Slopes toward the valleys are steep and unstable, and those toward the valley sides are shallow. Crests are boulder strewn and hummocky, and the ridges are encroached on by alluvial fans and talus cones. Farther north, morainal and glaciofluvial material appear to be more completely covered by tundra and lichens.

At least one terminal and one upstream lateral moraine along each of the creeks which drain Leffingwell, Arey, McCall, and Hubley Glaciers occur above 1, 1½, 3½, and 2½ miles respectively upstream from their mouths. A tributary moraine that cuts terminal moraines of the Fourth advance also occurs about 2 miles above the mouth of Hubley Creek. These are interpreted to be recessional moraines of the Fourth advance or to represent a readvance. These moraines seem to be intermediate in stability and amount of vegetation cover between those of Fourth and Fifth advances; they may be more closely related in time to the Fifth advance than to the Fourth advance end moraines.

CORRELATION

Kunkle (1958) considered the converging moraines 3–4 miles north of Okpilak Lake on the Okpilak River (here, the approximate limits of Fourth advance) as Itkillik recessional moraines, although he stated (p. 25) that he had previously considered the moraine 3 miles north of the lake as a younger Echooka River end moraine. He therefore considered Echooka River Glaciation to have reached only as far north as Okpilak Lake. However, I noted only one paired depositional terrace above the present floodplain terrace in the Okpilak Lake vicinity, whereas two distinct terrace levels are present within Kunkle's Echooka River Glaciation limits on the Jago River. I interpret this difference to indicate that, despite the outward similarity of the paired lakes along these river valleys, the lakes along the Okpilak River lie within limits of a glacial advance younger than that on the Jago River.

Kunkle (1958) correlated end moraines of this advance along McCall and Boulder Creeks with Alapah Mountain Glaciation. Keeler (1959, p. 92) indicated that the McCall Creek moraine is an Echooka River recessional moraine, but I interpret it to be a true end moraine representing a separate advance.

FIFTH ADVANCE

The youngest glacial advance, relatively minor and possibly very recent and of short duration, is correlated with Katak and Fan Mountain Glaciations. One terminal moraine adjoins all present glaciers. An end moraine also occurs as much as 1,000–2,500 feet downstream from most of the larger glaciers and is commonly separated from the upper terminal moraine by melt-water deposits and aufeis. Both moraines are fresh and unstable, and the lower one locally supports a few alpine plants. Upglacier, lateral moraines corresponding to the two end moraines are probably indistinguishable (fig. 6*B*). At higher altitudes, trimlines corresponding with tops of lateral moraines are easily distinguished above most glaciers by their barren, fresh appearance.

Determinations on the amount and rate of thinning and recession of Okpilak Glacier since 1907, as reported earlier (Sable, 1961), suggest that Fifth advance glaciation may have occurred in recent historic time. Recession of the terminus between 1907 and 1958 was reported to be 1,000±100 feet, 300 feet of which occurred between 1950 and 1956. Pronounced thinning has accompanied terminus retreat. All glaciers and evacuated cirques observed in the Romanzof Mountains show similar features and indicate a consistent pattern of very recent shrinkage. The Fifth advance did not reach the major river valleys except in their headwaters.

AGE AND CORRELATION SUMMARY

Correlation of Fifth advance with Katak Glaciation is certain. Fourth advance moraines are strikingly similar in size, position, and degree of modification to those of Peters Glaciation and also include deposits correlative with Alapah Mountain Glaciation (Reed, 1968, p. 67). Paired Fourth advance moraines may therefore represent two separate advances or a minor readvance or stillstand during general recession. Third advance deposits bear resemblances to Peters Glaciation within the mountains, but aerial photograph comparisons indicate that in its knob-and-kettle topography and broader extent north of the mountains, the Third advance also resembles Schrader Glaciation and may correspond to the Echooka River Glaciation of the central Brooks Range as it was formerly used there. There, Porter (1966, p. 58) equated his "Anivak Lake substage" of Itillik Glaciation with Echooka River Glaciation and considered this adance to be "merely an oscillation within the overall recessional phase of the Itkillik glaciation." In the Romanzof Mountains, Third advance deposits appear to be closely related in form, extent, and degree of modification to those of Second advance and, like Porter's interpretation, may represent a late recessional phase of that advance.

Most Second advance features, including the numerous recessional moraines, arcuate drainage patterns, and moderate degree of modification, closely resemble those described for Schrader Glaciation in the Mount Chamberlin area. Outer moraines and outwash 8-12 and 11-14 miles north of the mountains along the Jago and Okpilak Rivers, respectively, which are attributed to this advance, however, appear to be more highly modified than inner ones and may represent considerably older deposits, perhaps Chamberlin Glaciation equivalents. The areas of First advance deposits, correlated with Weller Glaciation by Sable (1965, p. 103-104), are here suggested to be attributable largely to Chamberlin Glaciation on the basis of aerial photograph comparisons of this area and the Mount Chamberlin area. However, they probably also contain patches of weathered till of Weller age, such as those along the mountain front in Okpirourak Creek drainage.

The most pronounced differences in present form, drainage characteristics, and weathering of the deposits appear to be between the First and Second advances. No suitable material for age dating was collected, although some peat occurs in First and Second advance areas. Evidence for comparison with the chronological sequence in central North America is not available from this area, although Holmes and Lewis (1961, p. 862-863) tentatively considered Weller Glaciation pre-Wisconsin age and the remaining glaciations, except for Katak Glaciation, as presumably Wisconsin age. If correlations of central and eastern Brooks Range sequences are reasonably correct, Porter's (1964) chronology, which is in part based on radiocarbon dates, indicates that Fan Mountain, Katak, and Alapah Mountain Glaciations are post-Wisconsin, the Echooka River, Peters, Itkillik, and Schrader Glaciations are Wisconsin, and the earlier Sagavanirktok River, Chamberlin, Anaktuvuk River, and Weller Glaciations are pre-Wisconsin.

ADJACENT AREAS AND ISOLATED DEPOSITS

East of the mapped area, deposits beyond the mountain front include strong morainal traces similar to those of the Second advance as much as 7 miles north of the mountains along an unnamed river, 22 miles east-northeast of Jago Lake. The intervening area contains bedrock hills and areas of well-integrated drainage probably veneered by deposits of First advance.

Bouldery morainal material in the headwaters of Okpirourak Creek between the Jago and Okpilak Rivers includes two pronounced sets of morainal ridges mapped with undivided glacial deposits on plate 1. They are tentatively considered end moraines of Third and Fourth advances. Deposits beyond these ridges and farther downstream 3 miles east of Okpilak Lake are considered to be Second advance deposits.

West of the Opilak River, only scattered granite erratics were observed, and those were along Old Man Creek. Gravel terrace remnants about 400 feet above the creek near the mountain front probably represent glaciofluvial deposits.

Glacial deposits along the Hulahula River were not visited in the field, but were studied through binocular examination and on aerial photographs. These studies indicate well-defined morainal traces, as high as 2,500-foot altitude and 1,300 feet above the river, that extend northward beyond the area and converge about 15 miles north of the mountain front. Their surface expression is similar to that of both the Second and Third advances. I infer that they are correlative with Second advance or Schrader Glaciation.

Much glacial material occurs in Hulahula River tributaries west and northwest of Mount Michelson. Esetuk Creek valley contains Fifth advance deposits adjoining the glaciers and a prominent lateral moraine 400-500 feet above the valley, which may represent Fourth advance. Less prominent but distinct moraines 500-600 feet above this generally resemble those of Third and Second advances; more highly modified morainal material which has spilled over the divides west of Esetuk Creek may reflect First advance.

ALLUVIAL AND TALUS FANS

Fans as much as 700 feet above stream level are well developed along the steep-walled river valleys within the mountains. Apexes of many fans correspond with interpreted and projected upper limits of the Second and Third advances and they consistently cover moraines of the Fourth advance.

Several fans examined in the upper part of the Okpilak River valley show features that indicate three stages of activity (fig. 6*A*). The oldest and usually marginal part of the fan is stable, the slopes average 10°-20°, and fan material is nearly covered by rock lichens and patchy tundra vegetation. In some fans the oldest part rests on moraine tops of the Fourth advance; in others the material has encroached to present river level. On black and white photographs these deposits are dark gray to black. Fan material of intermediate age, which is barely stable under a man's weight, supports a partial cover of rock lichens. This debris has spread in anastomosing patterns over the older portions. On photographs this material has a medium-gray hue. Modern talus and alluvial material, white to light gray on photographs, is highly unstable and without vegetation cover. Its pattern of encroachment is similar to that of the intermediate stage; it forms the apexes of active fans and occurs down to present river level.

Deposits in a fan 1½ miles north of the Okpilak River main fork were examined in a cut 20 feet high. Constituents of the fan material are subangular to subround and are made up of about 30 percent granite boulders as much as 3½ feet, and averaging 2 feet, in diameter; 20 percent cobbles (granite and minor limestone); 20 percent pebbles (80 percent granite, 20 percent quartz and limestone); and

30 percent sand (90 percent quartz, 10 percent feldspar and dark minerals). No stratification, soil layers, or other evidence for separating the material were observed.

GRANITIC ROCKS

INVESTIGATIONS

Granite in the Romanzof Mountains was first reported by Leffingwell (1919, p. 126–128), who briefly described the general features of the pluton along the Okpilak River and tentatively concluded that it was post-Mississippian in age. After examination of small areas of the granite along the Okpilak River and at one point east of the Hulahula River, Whittington and Sable (1948, p. 14–16) suggested that the pluton may have been emplaced prior to Mississippian time.

The 1957–58 and 1969 field studies of granitic rocks in the mapped area were semidetailed in nature; some limited areas were carefully studied, but large areas between traverses were not examined. The study was concentrated along the Okpilak River and its tributaries; less time was spent in the drainages of the Jago and Hulahula Rivers. At the stations occupied during fieldwork, all recognizable planar and linear elements were recorded, and several hundred specimens were collected. Fifty standard thin sections were examined, and crushed fragments of some minerals were identified by oil-immersion methods. Plagioclase feldspars were identified on the basis of extinction angles and refractive indices. A few minerals were identified by X-ray diffraction by B. L. Reed, U.S. Geological Survey. Analytical data include 21 modal analyses using the method described by Chayes (1949). Twenty-one chemical analyses were made by the U.S. Geological Survey, and their norms were calculated. Lead-alpha and potassium-argon age determinations were made on two samples of the granitic rocks.

The major problems relating to the granitic rocks are (1) those of composition and its bearing on origin of the granite, and (2) the time of granite emplacement relative to the one or more major orogenies that affected the area. In addition to the possibility of magmatic origin, either by crystallization of an allochthonous magma or by mainly autochthonous melting or mobilization, there is also the possibility of potash metasomatism during emplacement. Two distinct age possibilities for granite emplacement, middle to late Paleozoic and late Mesozoic, are suggested by radiogenic dating and contradictory field evidence. If granite emplacement occurred during a Paleozoic orogenic episode, a later Mesozoic orogeny has superimposed its effects on the area; if the granitic pluton is of Mesozoic age, then a virtually time-continuous but complex series of Mesozoic plutonic and deformational events is reflected by the major geologic features of the area.

NAMES AND TERMINOLOGY

No formal names are applied to the granitic rocks in this report, although the term "Okpilak gneissoid granite" was used by Whittington and Sable (1948) to designate the main granite mass between the Jago and Hulahula Rivers (pl. 1). The names Okpilak batholith and Jago stock, used here for the two larger bodies of granite exposed in the area (pl. 1), designate respectively the main exposed granite mass and the smaller body along the Jago River. The names refer to relative areal size of exposed granitic rocks as suggested by Daly (1933, p. 113); they have no genetic connotations, and it is not inferred that these are discrete bodies in the subsurface. The term "pluton" is used in a general sense to include these bodies and their presumed subsurface continuation.

The compositional classification for the granitic rocks is modal and is modified from Johannsen (1931). The terms "granite" or "granitic rock," when not used in a specific descriptive manner, are used interchangeably and include the family of granitoid rocks ranging from granitic to granodioritic composition. In this area the term also includes granite gneiss, schistose rocks of granitic composition, and quartz monzonite dikes. Grain-size terms for granitoid textures follow those of Johannsen (1931, p. 31). "Primary" is used to denote textures and structures interpreted to have formed during a stage of plastic crystalline flow of a melt or to represent replaced earlier features of granitized rocks. "Secondary" refers to textures and structures interpreted to have been superimposed on the pluton after emplacement. The terms "foliation" and "lineation" refer to parallelism of mineral components in the granitic rocks.

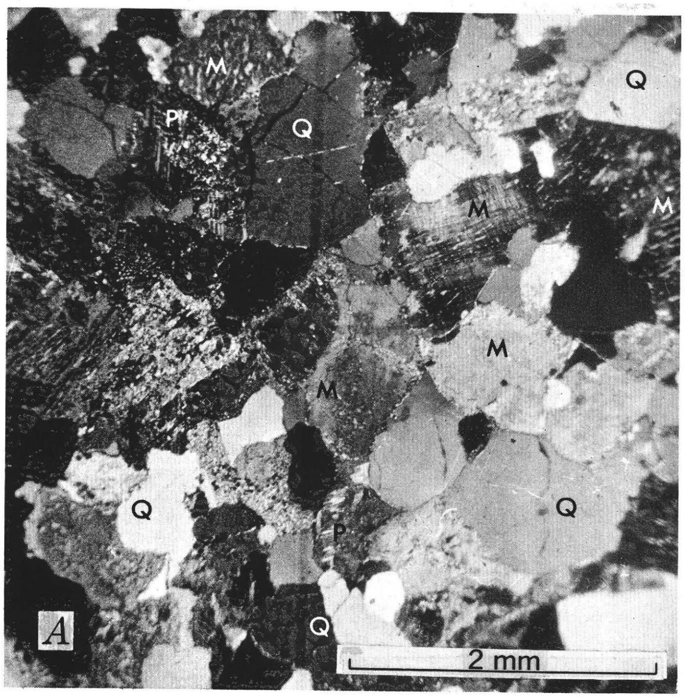
DISTRIBUTION AND OUTCROP

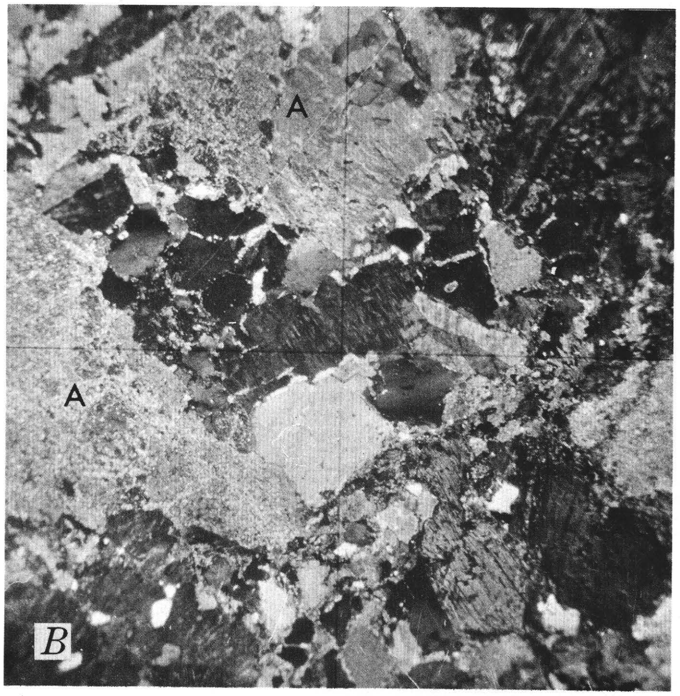
Granite in the mapped area is exposed in two main masses which occupy about 200 square miles (pl. 1). The Okpilak batholith is elongate, lies between the Jago and Hulahula Rivers, and occupies about 180 square miles of the highest and most rugged part of the Romanzof Mountains. The Jago stock, along the Jago River 13–18 miles south of Jago Lake, occupies about 16 square miles. One small area of granite is exposed north of the Okpilak batholith in the headwaters of Okpirourak Creek. A small exposure of granite, about 1,000 square feet in area, is present in the alluvial fan at the mouth of McCall Creek. This exposure is interpreted to represent an isolated bedrock outcrop, but it may be an unusually large glacial erratic. Other small exposures of granite are present about one-quarter mile east of the Jago stock along the sole of an overthrust block. Bedrock exposures are estimated to comprise about 50 percent of the granitic areas. Below altitudes of about 6,000 feet, bedrock is largely covered by rock lichens; above this altitude. exposures are clean but many are inaccessible.

A small stock of hornblende quartz monzonite about 7 miles south of the Jago stock was discovered by H. R. Reiser and me during a reconnaissance in 1969. Little is known about this body except that it is in part mineralogically different from the biotite granite and quartz monzonite of the Okpilak batholith and Jago stock and that it intrudes quartzitic rocks of the Neruokpuk Formation. A potassium-argon age determination of 431±13 m.y. (Silurian) for the horneblende has been reported by Reiser (1970, p. K4).

LITHOLOGY AND COMPOSITION

The granite in the Okpilak batholith and Jago stock is megascopically a light- to medium-light-gray, medium- to coarse-grained granitoid rock that contains essential potassium feldspar, quartz, plagioclase feldspar, and fresh to chloritized biotite in decreasing order of abundance. Textures include seriate types with large potassium feldspar megacrysts; gneissic, autoclastic(?) and cataclastic textures are common; and schistose granite is locally abundant. Equigranular nondirectional textures occur mostly in the interior parts of the pluton, but these appear to be subordinate to other textural varieties. Very fine to very coarse grained textures are abundant in some parts of the pluton, are mostly intergradational, and in some places alternate in a rough textural banding. Concentrations of biotite, resulting in compositional banding, are not as common as the textural variations. Inclusions and schlieren are locally common but not abundant. Aplite dikes are relatively abundant in some areas; pegmatites of normal granitic composition were seen at a few localities. Black tourmaline is locally common in several types of occurrence. Disseminated pyrite is locally abundant; magnetite, molybdenite, muscovite, sericite, and fluorite are less common. "Pink-and-green" granite, in which potassium feldspar is pink and plagioclase is green, comprises a very minor fraction of the pluton and is not considered a separate granite facies, but it is probably the result of deuteric alteration or later mineralizing effects. Dark dikes include quartz-monzonite and dikes of mafic





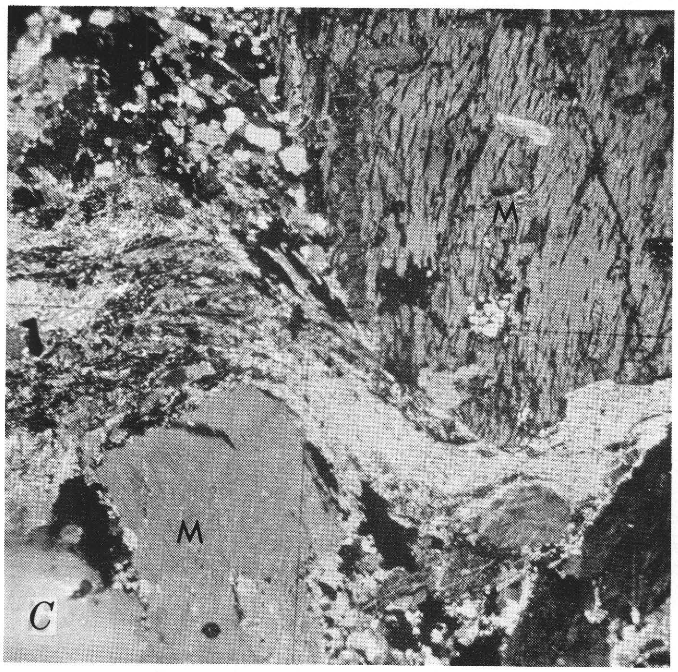


FIGURE 7.—Textures in granite of Okpilak batholith. Crossed polars. *A*, Anhedral-equigranular texture along Jago River tributary. M, Microline; Q, quartz; P, plagioclase. *B*, Schistose granite on east side of Okpilak River. Areas (A) at left and top are mixtures of sericite, chlorite, and quartz. *C*, Shear zone between microcline megacrysts (M) composed of sericite, shredded biotite, and quartz; Okpilak River, east fork. All photos at same scale.

composition which cut granite (p. 60–61). Some schistose rocks in the granite probably represent altered metasediments.

The photomicrographs (fig. 7) illustrate some of the textures and mineral associations in the granitic rocks.

MINERALOGY

Essential minerals in the granitic rocks are perthitic microcline, quartz, plagioclase, and titaniferous(?) biotite. Horneblende is scarce. Accessory minerals include zircon, apatite, tourmaline, sphene, garnet, magnetite, ilmenite(?), calcite, monazite(?), and allanite(?). Alteration products are sericite, chlorite, calcite, epidote, pyrite, iron oxides, kaolinite, and leucoxene. Quartz, calcite, chlorite, tourmaline, fluorite, epidote, sericite, and ore minerals occupy veins.

MICROCLINE

Microcline occurs as large ovoid to euhedral megacrysts characteristic of the porphyritic texutral facies (p. 39), and as anhedral to euhedral groundmass grains. It is predominantly perthitic, commonly containing 5–30 percent albite, and is in small part granophyric. Zonally arranged inclusions of quartz occur within many crystals. Microcline is commonly poikilitic, containing albite-oligoclase patches and inclusions which are optically continuous both mutually and with adjoining grains of similar plagioclase. In different thin sections, all stages from patchy microcline in the interior of plagioclase crystals to microcline with a few plagioclase patches were seen. Albite twinning in the patches is commonly parallel to one direction of microcline twinning, but individual twins of separate plagioclase patches are not continuous. A few small biotite and muscovite inclusions are also present. Microcline is commonly cloudy and it shows wavy extinction and commonly carlsbad twinning. The gridiron twinning ranges from conspicuous to very obscure. Quartz veinlets cut microcline in some sections.

The rounded edges and corners of microcline megacrysts are commonly bounded by equigranular microaggregates of the essential minerals, streaks of sericite, and, less commonly, concentrations of biotite, which wrap about the corners of the megacryst. These aggregates in severely deformed granite represent mortar structure in some sections, and many of the rounded megacrysts are interpreted to have formed as the result of movements in the late stages of, or after, their crystallization.

Partial alteration of potassium feldspar to kaolinite is common. In some sheared zones, the megacrysts show alteration from fresh microcline to flattened green or white "ghosts" composed entirely of chlorite and (or) sericite and quartz (fig. 8). Microcline is also sparser in veinlets intergrown with quartz, calcite, and epidote; no perthitic intergrowths were seen in this variety.

PLAGIOCLASE

Plagioclase is generally subhedral; it occurs mostly in the groundmass but also as larger, nearly euhedral single or interlocking crystals. Its composition is mostly albite and oligoclase (An_6 to An_{12}, mostly An_8). Plagioclase in small groundmass grains appears to be more sodic than

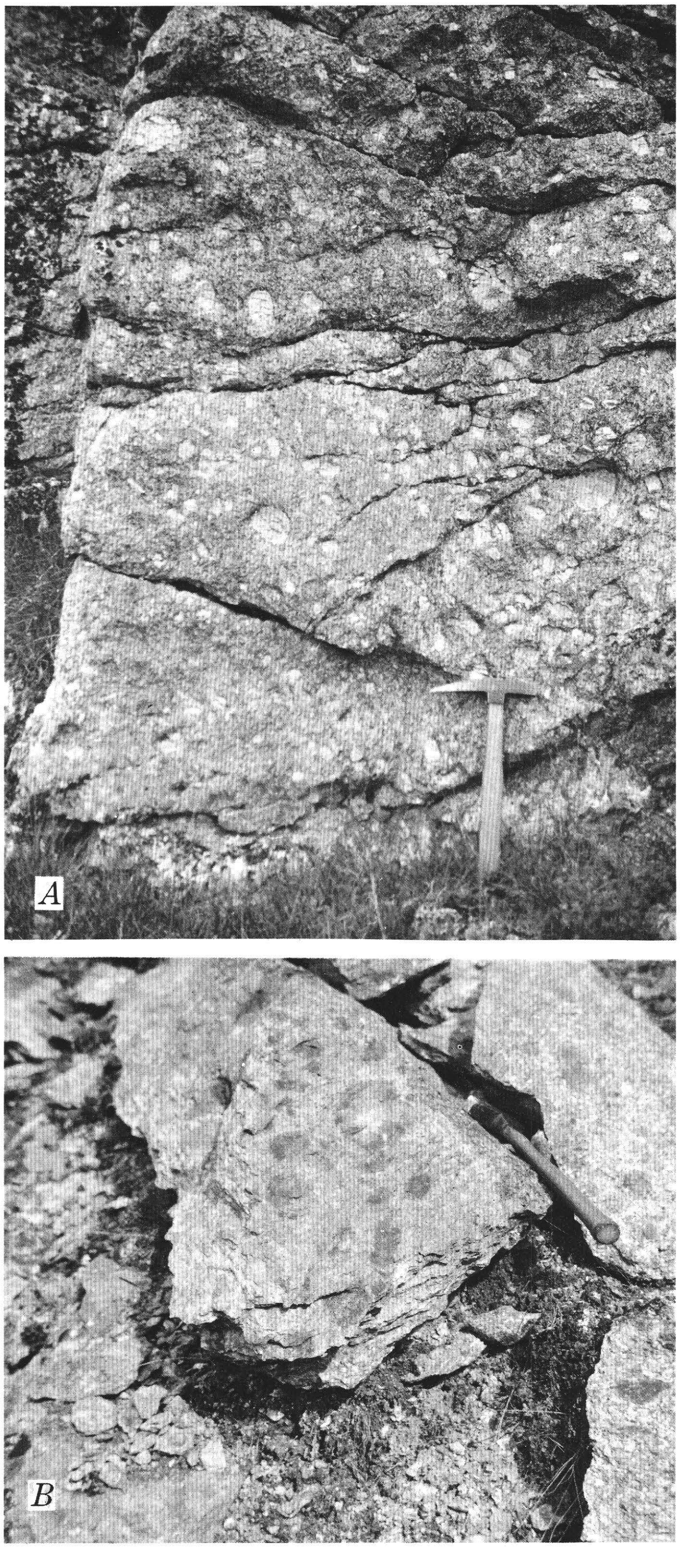


FIGURE 8.—Alteration in porphyritic granite, Okpilak River. *A*, Unaltered potassium feldspar megacrysts in massive granite. *B*, Flattened relict megacrysts composed of chlorite and sericite in schistose granite.

that of larger crystals; the small grains are also more commonly anhedral. A few crystals are normally zoned; these, as well as unzoned crystals, commonly contain highly sericitized inner cores of probably more calcic oligoclase. Crystals commonly display untwinned reaction rims of sodic albite (An 4?), the outer boundaries of which form irregular embayments with microcline and, very rarely, quartz. In some sections, however, nearly euhedral crystals of plagioclase exhibit no zoning or albite rims. Plagioclase is rarely myrmekitic and antiperthitic, and it contains a few biotite inclusions. Albite twins are common, carlsbad twins less so, and pericline twins rare. Plagioclase is altered in varying degree to sericite, mixtures of sericite and calcite, and, in "pink-and-green" granite, it is partially saussuritized to sericite, chlorite, and epidote.

QUARTZ

Quartz occurs as large anhedral grains, in interstitial microcrystalline aggregates, as subhedral to euhedral megacrysts as much as 1 inch in diameter, and in several types of veins and veinlets singly or associated with tourmaline, chlorite, calcite, sericite, epidote, fluorite, and ore minerals. Wavy extinction occurs in all quartz grains that are large enough to show this feature. Randomly distributed microlites such as rutile are common in larger grains; trains of microlites are present in quartz that shows pronounced strain effects (fracturing, irregular wavy extinction, and biaxial character). At least two, and perhaps more, generations of quartz are present in the granitic rocks; large quartz grains and quartz megacrysts are interpreted to be early; aggregates of small grains and quartz veinlets in feldspars, which together give high percentages of quartz in some modal analyses, are later. In some thin sections, quartz, quartz-sericite, and quartz-calcite-chlorite veinlets also cut grains of all essential minerals.

MICAS

Under the microscope, unaltered biotite is light brown ($n\gamma$=1.657-1.662). It also exhibits pale-green to light-olive hues ($n\gamma$=1.636–1.651), probably the result of alteration. Grains are mostly subhedral, commonly bent to shredded, and they commonly enclose abundant aggregates of sphene, euhedral to subround zircon grains with halos in fresh biotite, euhedral apatite, and needlelike inclusions. Partial or complete alteration of biotite to chlorite or to muscovite and sericite is common. The muscovite contains relict inclusions of abundant white opaque material, probably leucoxene after granulated sphene, as coating or along cleavage planes. Magnetite is commonly associated with altered biotite.

Muscovite occurs in small areas of granite greisen along with tourmaline, quartz, fluorite, magnetite, and pyrite. No inclusions were seen in this mica variety.

SEQUENCE OF CRYSTALLIZATION

The sequence of mineral development in the granitic rocks of this area is uncertain. Textural and mineral grain relationship features might be interpreted as a result of either melt crystallization or of metasomatism. I believe that most of the granite was derived from crystallization of a mobile body, but that granitic rocks along some margins of the pluton represent altered country rock.

Most of the feldspar relationships suggest that potassium feldspar formed late, in part as a replacement of plagioclase. The evidence includes (1) optically continuous islands of albite-oligoclase in microcline (fig. 9*A*), (2) irregular embayments between microcline and plagioclase in which plagioclase orientation corresponds with plagioclase islands in the microcline grains, (3) megacrysts with "cores" of sericitized plagioclase entirely or nearly enclosed by microcline (fig. 9*C*), (4) albite rims on plagioclase which in nearly all occurrences adjoin microcline and imply a reaction other than simple late-stage unmixing, and (5) sieve structure in microcline megacrysts, with fine-grained groundmass grains parallel to crystal boundaries (fig. 10*A*, *B*). Some relationships that do not suggest that potassium feldspar was late and a replacement of plagioclase are: (1) in some thin sections, feldspars occur as discrete grains intergrown with other essential minerals and show no evidence of reaction or replacement (fig. 7*A*), (2) a small number of plagioclase crystals exhibit albite rims along boundaries with quartz as well as microcline, and (3) some plagioclase appears to have replaced microcline (fig. 9*B*). This third relationship may be evidence of a late stage of albitization following crystallization of potassium feldspar.

The sequence of crystallization in the granite is believed to have been, from oldest to youngest:

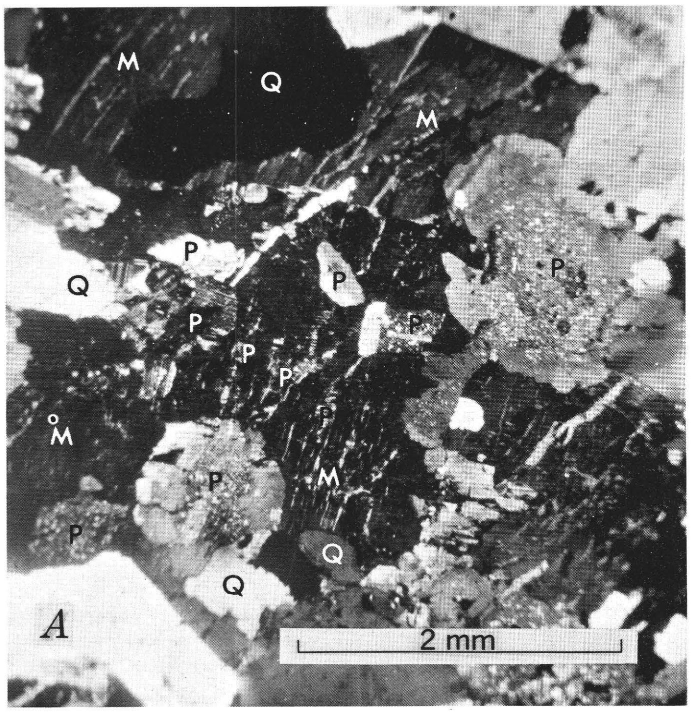
1. Euhedral zircon, apatite, and magnetite.
2. Plagioclase megacrysts, including cores of zoned crystals, and myrmekite. Biotite.
3. Potassium feldspar, in part replacing plagioclase, with formation of perthite and albite rims.
4. Quartz, as large anhedral and euhedral grains.
5. Main formation of groundmass minerals in rocks of bimodal grain size.
6. Continued growth of microcline crystal margins; anhedral quartz grains and quartz veinlets in feldspars.
7. Partial replacement of microcline by albite?
8. Deuteric and hydrothermal mineral alterations, replacements, and introductions, perhaps in part not related to granite emplacement. Tourmaline; chlorite, muscovite, sericite, and magnetite after biotite; sericite and epidote after plagioclase; vein- and some groundmass-quartz; fluorite; sulfides.

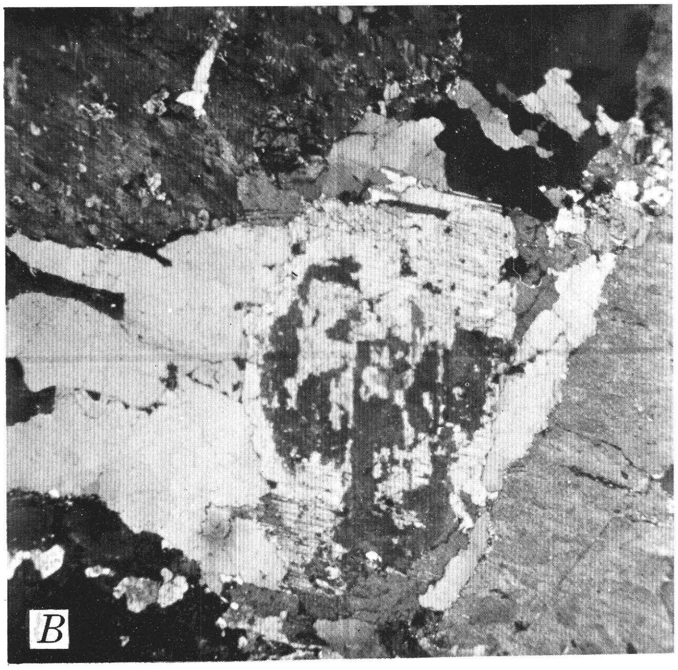
Although the preceding sequence implies melt crystallization, potassium metasomatism may have been an important process marginal to the main pluton. The growth of the abundant perthitic microcline megacrysts as porphyroblasts is reasonable, if the criteria proposed for features of that origin are valid (Goodspeed, 1948, p. 66–67; 1959, p. 247–248). Such features as crystalloblastic aspect, sieve structures, and accompanying shredded biotite and seriate textures are common in the granitic rocks discussed here. Microcline megacrysts are present in inclusions within the granite, in Neruokpuk Formation quartzites short distances from the granite contact, and in the marginal porphyritic facies of the granite itself.

MODAL COMPOSITION

Results of modal analyses of 21 representative samples from the Okpilak batholith are shown in table 8 and, recalculated to 100 percent quartz-potash feldspar-plagioclase, their distribution is shown in figure 11; sample localities are shown on plate 1. Apparent trend of the modes are shown by a trend line drawn by inspection (fig. 11).

The average mode of the 21 analyses is 33.4 percent microcline, 26.6 percent plagioclase, 33.0 percent quartz, and 5.1 percent biotite. Most samples are quartz monzonites; a few are granite; six samples show microcline and plagioclase percentages within 2 percent of one another. The average percentage of modal quartz, potassium feldspar, and plagioclase feldspar recalculated to 100 percent are 34.9, 35.7, and 29.4 percent, respectively; this composition is that of a quartz monzonite. Most analyses fall in a rather restricted area (fig. 11) and reflect a limited compositional range for the pluton. The number of samples is insufficient to delineate relationships between compositions and textural facies, if such exist; the results suggest, however, that biotite content is relatively high in coarse-grained and porphyritic granite, and that quartz and microcline may be more abundant in coarse-grained granite.





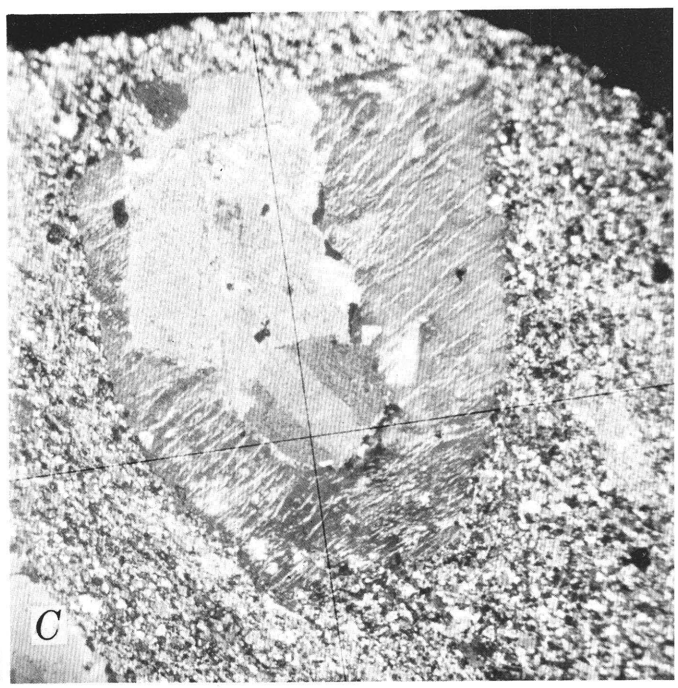


FIGURE 9.—Perthitic microcline and plagioclase intergrowths or replacements. Crossed polars. *A*, Anhedral microcline grain (dark with patchy optically oriented plagioclase and other plagioclase inclusions. M microcline; P, plagioclase; Q, quartz. Hubley Creek, B., Plagioclase crystal partly enclosing patchy microcline (dark). Hubley Creek. *C*, Euhedral perthitic microcline crystal nearly enclosing sericitized plagioclase in fine groundmass showing "flow" texture. Arey Creek. All photos at same scale.

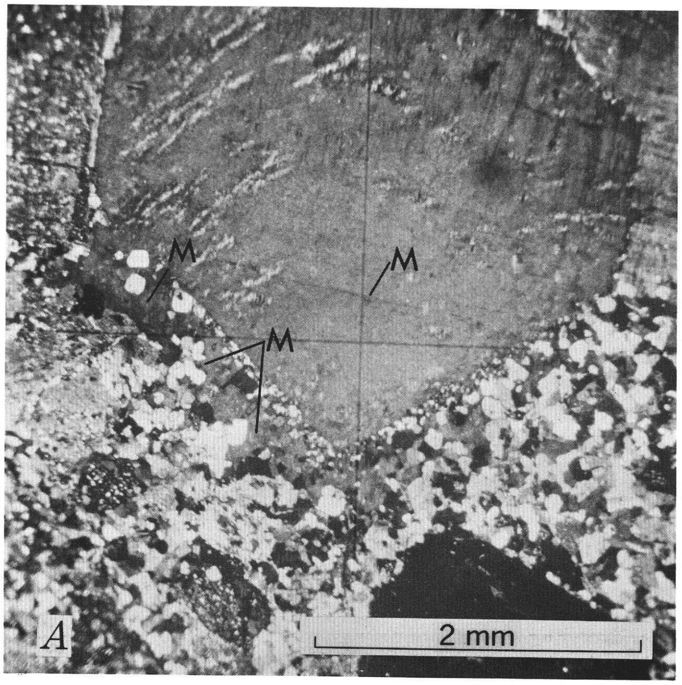
A few samples show quartz content which seems excessive, compared to that of many analyzed granitic rocks reported in the literature. Although the modes exclude vein material and minor accessories such as granophyric quartz, all other quartz is included. Some of the interstitial microaggregate material, dominantly quartz, probably crystallized during the late stages of emplacement; some may have been introduced after consolidation. High microcline content in a few samples also may

TABLE 8.—*Modal analyses of granitic rocks from Okpilak batholith, Romanzof Mountains*

[Tr, trace]

Field sample No.	Micro-cline	Plagio-clase	Quartz (includes micro-quartz)	Bio-tite[1]	Tourma-line	Microquartz (included in quartz)	Granite textural facies
Granite							
57ASa35	51.3	26.0	15.6	7.0	None	Tr	Variable.
67	48.3	18.9	16.0	5.1	None	Tr	Coarse.
58ASa60	42.7	17.8	31.9	7.6	None	None	Coarse.
Quartz monzonite							
57ASa73	46.8	28.4	23.3	1.4	None	None	Variable.
74	44.6	27.4	26.2	1.8	None	None	Do.
58ASa182(1)	39.1	22.4	33.5	5.0	None	21.0	Coarse.
57ASa73	37.7	27.6	32.2	2.5	None	None	Variable.
58ASa68	35.2	26.2	34.5	2.8	None	None	Do.
40	33.8	27.4	33.0	5.8	None	None	Do.
19	33.6	28.0	29.1	7.8	None	Tr	Porphyritic.
65	32.2	31.5	32.4	2.9	0.2	None	Variable.
57ASa146	29.9	27.9	36.9	5.4	None	Tr	Do.
58ASa35	29.7	24.4	37.6	5.8	None	24.1	Variable?
57ASa70	27.1	32.2	34.6	6.0	Tr	None	Variable.
58ASa182(2)	25.9	25.4	36.9	7.8	Tr	24.5	Coarse.
57ASa89	26.0	24.0	45.8	4.1	None	None	Porphyritic.
300	25.9	24.4	42.1	7.6	None	Tr	Coarse.
23	24.5	32.9	34.5	8.2	None	None	Porphyritic.
141	23.9	36.6	31.8	7.8	None	11.6	Do.
58ASa111	23.5	23.5	47.1	5.9	None	None	Variable.
57ASa75	19.1	26.5	38.8	...	15.2	None	Do.

[1]Includes alteration products and inclusions.



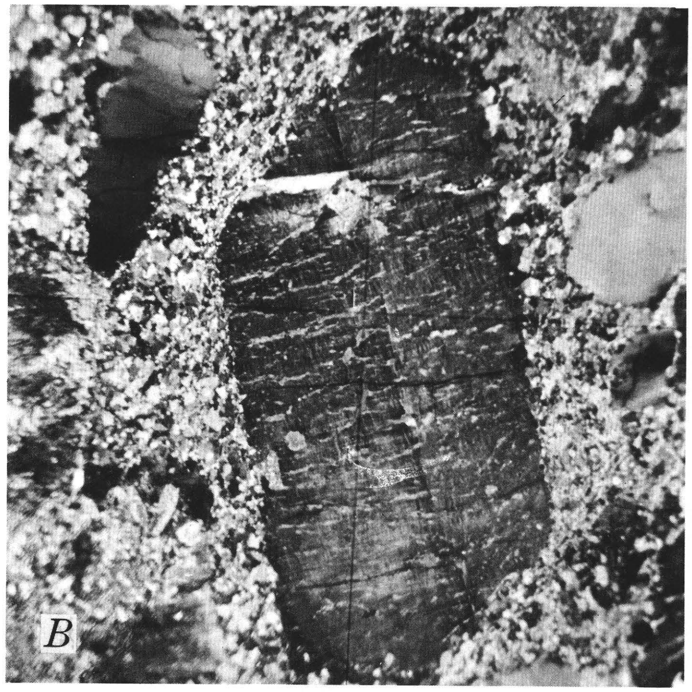


FIGURE 10.—Perthitic microcline megacrysts in granite. Crossed polars. *A*, Euhedral crystal showing marginal growth (M) into fine-grained dominantly quartz groundmass. Okpilak River, east fork. *B*, Euhedral crystal with rounded corners possibly the result of granulation. Arey Creek. *C*, Ovoidal megacryst showing marginal growth into fine groundmass. Optically oriented plagioclase (P) within crystal. Small square area (S) is sericitized plagioclase not oriented with long axis of megacryst. Creek four miles south of Okpilak Lake. All photos at same scale.

not accurately reflect composition of rocks at the sample locality but may indicate locally abnormal concentrations of small microcline megacrysts. Microcline megacrysts may be porphyroblasts, the result of potash metasomatism, as their presence in country-rock inclusions suggest. High percentages of quartz and microcline may also reflect contamination of a melt by quartzose-feldspathic rocks or, less likely, the possibility that the analyzed rocks represent paragneiss.

CHEMICAL COMPOSITION

Results of 21 rapid-rock chemical analyses are given in table 9, and sample localities are shown on plate 1. All the samples except 58ASa61 were relatively unaltered granitic rocks selected as representative samples after examination of thin sections. Sample 58ASa61, is a bleached and pyritized granite analyzed for comparison with the adjoining unaltered sample 58ASa60, is discussed on page 69. Calculated CIPW norms from these analyses are also shown in table 9, and, except for sample 58ASa61, modal and normative ratios are plotted on the distribution diagram (fig. 11).

INTERPRETATION OF MODAL AND CHEMICAL DATA

The limited data in the modal and chemical analyses suggest several generalizations:

1. Considering the size of the pluton and the analytical techniques, the variations among the oxides in most of the samples analyzed are small. The modal analyses show greater scatter than the norms, but most

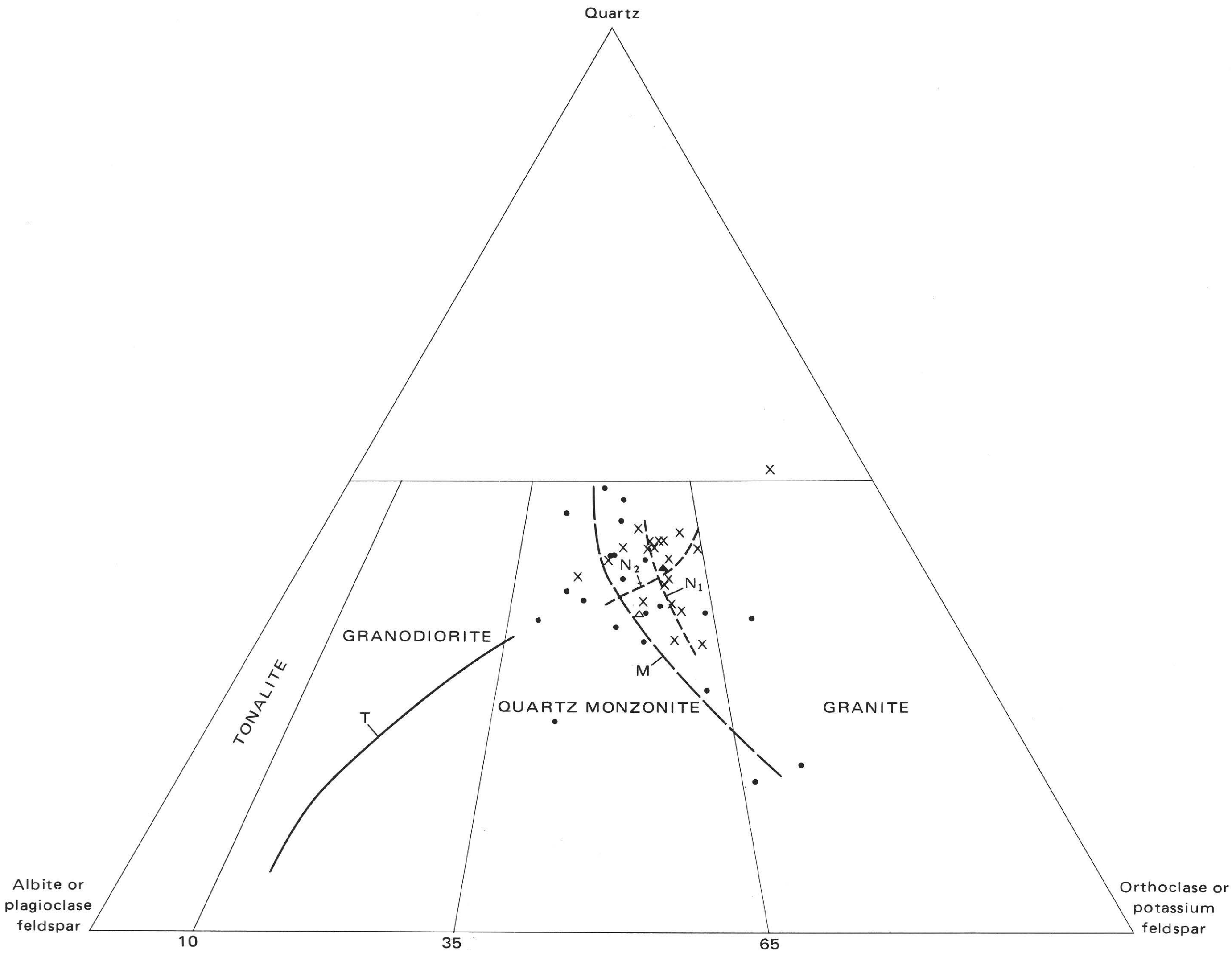


FIGURE 11.—Diagram showing distribution of leucocratic constituents for 21 modal analyses and 20 normative compositions of granitic rocks from the Okpilak batholith, and possible trend lines. Points indicate modal compositions; open triangle indicates their average; dashed line M is their trend line. x's indicate normative compositions; solid triangle indicates their average; dashed lines N_1 and N_2 are their possible trend lines. Line T is trend line of norms of granitic rocks from Colville and other batholiths in north-central Washington, used as reference by Moore (1959).

TABLE 9.—*Chemical analyses and normative composition of granitic rocks from Okpilak batholith and Jago stock, Romanzof Mountains, Alaska, and averages of some other granites reported in the literature*

[Explanation of symbols: Textural facies—V, variable; P, porphyritic; C, coarse. In figure columns, leaders (...) indicate no data]

Field No. (and loc. No. pl. 1)	57ASa- 30	57ASa- 34	57ASa- 46	57ASa- 52	57ASa- 65	57ASa- 68	57ASa- 70	57ASa- 104	57ASa- 112	57ASa- 116	57ASa- 133(6)	57ASa- 138	57ASa- 142	58ASa- 34	58ASa- 47	58ASa- 60	58ASa- ([2])61	58ASa- 76	58ASa- 114(2)	58ASa- 176	58ASa- 182	Averages (number of analyses in brackets): This report [21] (58ASa-61 excluded)	Nockolds (1954) [3][37]	Nockolds (1954) [4][12]	Sainsbury and others (1968) [5][6]
Laboratory No.			M106-			M106-	156-			M106-			156-		M106-	156-	156-		M106-		156-				
	878W	879W	880W	881W	([1])	883W	463	885W	886W	887W	888W	889W	465	890W	891W	460	461	892W	893W	894W	464				
Textural facies	V	V	V	V	V	V	V	V(?)	V	P(?)	P	P	P(?)	V	V	C	C	P	V	V	C				
Chemical analyses (in percent) [Analyses by rapid rock method described by Shapiro and Brannock (1956); analysts, P. L. D. Elmore, S. D. Botts, I. R. Barlow, G. W. Chloe, James Kelsey, H. Smith, John Glenn, and Lowell Artis, U.S. Geological Survey]																									
SiO_2	73.9	73.4	73.6	75.0	76.4	68.9	76.0	66.6	72.8	75.0	71.0	69.0	74.7	75.9	73.4	73.2	78.3	73.8	72.0	72.3	75.5	73.2	73.28	75.01	74.1
Al_2O_3	13.4	13.4	13.7	12.9	12.2	14.8	13.1	15.3	13.0	13.0	13.4	14.4	12.8	12.4	13.3	13.5	11.2	12.3	13.2	13.9	11.8	13.3	13.33	13:16	13.7
Fe_2O_3	.40	.39	.78	.36	.54	.67	.90	.85	.62	.36	.58	.85	1.0	0	.36	.80	.20	2.5	.84	0	.60	.67	.87	.94	.31
FeO	1.0	1.1	1.2	1.4	.98	2.3	.22	2.5	1.8	1.4	2.2	2.5	.73	1.1	2.2	1.1	<.05	.64	1.6	1.6	1.6	1.5	1.38	.88	1.01
MgO	.42	.54	.43	.40	.25	.88	.15	1.5	.61	.45	1.0	1.1	.35	.18	.59	.54	.27	.10	.60	.50	.31	.54	.50	.24	.43
CaO	1.2	1.4	.55	.71	.90	1.8	.40	2.8	1.5	.50	2.0	1.9	1.3	.71	.69	.53	.26	.93	1.8	1.4	1.1	1.2	1.17	.56	.77
Na_2O	1.0	2.2	2.7	2.6	2.6	2.5	3.3	2.5	2.4	2.2	2.6	2.7	2.6	2.7	2.4	2.7	5.4	3.6	2.5	2.7	2.4	2.5	2.96	3.48	3.8
K_2O	5.8	5.1	5.5	5.0	4.6	5.9	4.6	5.1	5.0	5.6	4.0	4.7	4.8	5.0	4.8	5.9	.70	4.1	5.1	5.4	4.9	5.4	5.52	5.01	4.7
H_2O-	.07	.07	.08	.06	.03	.03	.72	.05	.06	.06	.05	.07	.72	.03	.04	.86	.57	.04	.05	.06	.73	.....	.....	.....	.....
H_2O+	1.1	1.0	.91	.93	.89	.33		1.1	.90	.76	1.5	.92		.77	1.1			.72	.83	.79		.....	.50	.37	.73
TiO_2	.22	.21	.26	.21	.17	.49	.04	.44	.34	.24	.44	.51	.21	.08	.32	.24	.33	.10	.30	.23	.24	.26	.30	.17	.11
P_2O_5	.07	.07	.08	.07	.04	.17	.01	.16	.12	.08	.16	.17	.06	.02	.09	.07	.02	.04	.11	.08	.07	.09	.14	.11	.02
MnO	.04	.07	.07	.04	.04	.06	.04	.06	.06	.04	.06	.06	.04	.06	.07	.04	.02	.02	.08	.05	.06	.05	.05	.07	.04
CO_2	.80	.86	.10	.21	.06	.28	.13	.62	.09	.10	1.0	.18	<.05	.24	.05	.13	<.05	.15	.06	.05	<.05	.21	.....	.....	.....
FeS_2 [4]	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.08	2.0	.....	.....	.....	.....	.....	.....	.....	.....
Total	99.42	99.81	99.96	99.89	99.61	99.11	99.61	99.58	99.30	99.79	99.99	99.06	<99.36	99.19	99.41	99.69	99.37	99.04	99.07	99.06	99.36				
Normative composition (in percent)																									
Q	44.81	39.25	34.99	38.55	40.94	26.75	38.94	25.08	35.37	38.75	34.51	29.43	38.62	39.40	37.82	32.79	44.88	35.91	33.12	31.66	39.87	35.83	31.2	34.1	.....
C	5.35	3.88	2.73	2.58	1.42	2.10	2.32	2.41	1.42	2.84	1.79	2.26	1.24	1.87	3.25	2.23	1.29	.70	.70	1.39	.84	2.17	.5	1.3	.....
or	34.50	30.21	32.54	29.60	27.66	35.19	27.49	30.28	29.77	33.18	23.87	28.06	28.75	29.80	28.54	35.67	4.27	24.47	30.43	32.23	29.36	30.08	32.8	29.5	.....
ab	8.52	18.66	22.87	22.04	22.55	21.35	28.24	21.25	20.46	18.67	22.21	23.08	22.30	23.04	20.44	23.37	47.20	30.77	21.36	23.08	20.59	21.74	25.2	29.3	.....
an	.44	1.05	1.58	1.74	3.82	6.11	1.11	8.97	6.13	1.33	8.32	7.25	5.82	1.89	2.53	1.38	.87	3.44	7.91	6.17	4.75	4.09	5.0	2.2	.....
en	1.05	1.35	1.07	1.00	.63	2.21	.38	3.75	1.53	1.12	2.51	2.77	.88	.45	1.48	1.38	.69	.25	1.51	1.26	.78	1.37	1.3	.6	.....
fs	1.22	1.48	1.26	2.00	1.17	3.00	0	3.29	2.36	1.96	2.97	3.19	.24	2.02	3.36	1.06	0	0	1.92	2.68	2.19	1.87	1.3	.7	.....
mt	.58	.57	1.13	.52	.79	.98	.73	1.24	.91	.52	.85	1.24	1.47	0	.52	1.19	0	1.86	1.23	0	.88	.86	1.2	1.4	.....
hm	0	0	0	0	0	0	.41	0	0	0	0	0	0	0	0	0	<.05	<.05	0	0	0	<.05	.....	.....	.....
il	.42	.40	.49	.40	.31	.94	.78	.84	.65	.46	.84	.98	.40	.15	.61	.47	.15	.19	.57	.44	.46	.54	.6	.3	.....
ru	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	.26	0	0	0	0	<.05	.....	.....	.....
ap	.17	.17	.19	.17	.09	.41	.02	.38	.29	.19	.38	.41	.14	.05	.21	.17	.05	.10	.26	.19	.17	.21	.3	.3	.....
cc	1.83	1.96	.23	.48	.14	.64	.30	1.42	.21	.23	.23	.41	.11	.55	.11	.30	.12	.34	.14	.11	.11	.49	.....	.....	.....
Total	98.89	98.98	99.08	99.08	99.52	99.68	100.72	98.91	99.10	99.25	98.48	99.08	99.97	99.22	98.87	100.01	<99.83	<98.08	99.15	99.21	100.00	<99.35	99.4	99.7	.....

[1]Average of two analyses, Nos. M106-882W and 156462.
[2]Altered granite.
[3]Biotite calc-alkali granite.
[4]Total sulfur calculated to FeS_2.
[5]Seward Peninsula, Alaska, biotite granites.

of these also reflect a limited composition for the granitic rocks.

2. Although the average of the oxides in the granitic rocks indicates calc-alkali biotite granite composition, several samples have chemical compositions very similar to the average biotite alkali granite of Nockolds (1954, p. 1012), and also to the average of six biotite granites reported from the Seward Peninsula, Alaska, by Sainsbury, Hamilton, and Huffman (1968, p. F8). The possibly anomalous tin and beryllium content reported in the stream sediments (Brosgé, and others, 1970) and the tourmaline and fluorite occurrences in the Romanzof Mountains all indicate a biotite granite, perhaps, like those on the Seward Peninsula, of the tin-bearing variety.
3. Apparent compositional trends suggest that the granite is the product of more than simple melt crystallization. The possible normative compositional trends of the granite, by themselves (fig. 11, lines N_1, N_2), are not clearly defined, but apparent trends are indicated when modal compositions (fig. 11, line M), or modal and normative ones considered together, are plotted. Although modal compositions cannot be directly compared to normative ones, general comparisons of quartz-orthoclase-plagioclase ratios of modes and norms of a few samples from the same outcrop vicinity in the area indicate that differences between these modal and normative ratios are less than 10 percent. Thus, with the assumption that the modal compositions generally reflect the norm compositions, a considerable scattering of values is evident in figure 11, and an apparent trend line, M, can be drawn.

If trend line M in figure 11 represents a single differentiation cycle, two factors become apparent: (1) the original magmatic material must have been potassium rich, and (2) the final material is quartz rich. Microcline megacrysts could therefore be early phenocrysts, with crystallization progressing toward higher quartz-albite compositions. Petrographic evidence, however, indicates that crystallization of much of the plagioclase feldspar preceded formation of microcline; the presence of microcline megacrysts in granite, in inclusions in granite, and in country rock may suggest potassium metasomatism. The relatively high quartz values and bimodal grain size in many samples also suggest factors that relate to a more complex origin than a single magmatic differentiation cycle.

Considering the composition, contact relationships, textures, and internal structural features of the pluton, I conclude that the granite is mostly a product of melt crystallization but that assimilation of siliceous and feldspathic country rock (such as the felsic graywackes of the Neruokpuk Formation) by the melt or late-stage introduction of silica has resulted in high quartz values, and that potassium metasomatism, best expressed in the outer marginal zone of the pluton, has resulted in high potassium values.

TEXTURAL FACIES

Although there appears to be little mineralogical or chemical variation in the granite of the Romanzof Mountains, the Okpilak batholith and the Jago stock exhibit textural varieties whose areal patterns appear to be roughly consistent within the pluton. Three textural facies, shown on plate 1, are (1) a locally developed marginal *porphyritic* granite facies characterized by abundant large microcline megacrysts, (2) a middle to marginal *variable* facies of fine- to coarse-grained granite exhibiting alternations in grain size, and (3) an inner to marginal *coarse* facies of dominantly medium- to very coarse-grained equigranular to porphyritic granite. Contacts between the facies are approximate, and those between the variable and coarse facies are largely inferred.

The porphyritic facies is mostly medium- to coarse-grained granite characterized by conspicuous, large microcline megacrysts. This facies occupies the outer 300 to 6,000 feet (plan view) of the Okpilak batholith but is locally absent on the east and west flanks of the body and was not recognized along the south margin west of the Okpilak River. These rocks also occur in the eastern part of the Jago stock. Aplite dikes and inclusions of country rock are relatively common in this facies. Microcline megacrysts, as much as 3 inches in maximum dimension, constitute an estimated 10–30 percent of the rock. They are euhedral-tabular to subspheroidal; most of them are tabular with well-rounded edges. Some enclose biotite flakes and some are fringed by concentrations of biotite.

Although in some areas microcline megacrysts are little altered or deformed, they commonly show strain effects ranging from wavy extinction and small dislocations along cleavage planes to the production of augen, mortar structure, and mylonite.

The variable facies of the granite probably constitutes the largest areas of exposure and is characterized by medium- to fine-grained granite and lesser amounts of coarse-grained granite. These intergrade or locally alternate in a banded textural pattern. Aplite dikes appear to be relatively abundant in this facies, as are banded concentrations of biotite and tourmaline and deuteric or later minerals. Whether these features are in reality more limited to the variable facies or were simple observed more often because these rocks are more accessible to study than the coarse facies is uncertain.

The variable facies grades outward and probably upward into the marginal porphyritic facies. Microcline megacrysts, although locally common in the variable facies, are less abundant and smaller than those of the porphyritic facies; they rarely exceed 1 inch in greatest dimension and are commonly euhedral. I believe that the interpretation of primary granite structures is more valid in the variable facies than in the other facies, although dislocations and secondary foliation commonly interrupt or obscure the primary features. Variable-facies-type granite is locally present along the borders of the Okpilak batholith, notably the east and west margins, where the contact rocks clearly show intrusive and contact effects.

Coarse facies granite may comprise several areas in the interior of the Okpilak batholith as well as the central part of the Jago stock. The granite is dominantly coarse to very coarse grained. In some parts of the area, as in the vicinity of McCall Glacier cirques, it lacks discernible linear or planar directional elements; in others it is gneissic and cataclastic. In the Okpilak batholith the areas that appear to consist of this facies (pl. 1) are those northeast of McCall Glacier, the northern part of the batholith west of the Okpilak River, and southern part of the batholith along the Okpilak River, A fourth possible area may lie in the western part of the batholith, as inferred from abundant coarse-grained granite in glacial debris from this source.

Definitive mappable contacts between the coarse and variable facies of the granite were not seen, and the facies may be gradational or interfingering. In some parts of the mapped area, however, as between McCall Glacier and Arey Creek, sharp irregular contacts between fine- and coarse-grained granite were locally observed. These may represent crosscutting relationships near the facies boundary. Field photographs of the textural variations in the three facies are shown in figure 12.

Some dark schistose rocks that contain quartz and microcline megacrysts occur within the porphyritic facies and probably represent altered metasediments. The variable facies also includes some belts of quartz-muscovite schist, as along Leffingwell and Esetuk Glaciers. Contacts between these rocks and granite are obscure; some are interfingering, and others seem to be gradational. Textural gradations in the variable facies are interpreted to represent flow structure, but they may also be segregation banding or relict structures of granitized rocks.

The porphyritic facies may represent either (1) an early fluid phase of melt influx with resulting large feldspar phenocrysts, a congealing shell which partly enclosed the variable facies, the latter characterized by considerable variation of volatiles and stress-temperature conditions, or (2) in part, a granitized paragneiss, grading inward into the variable facies, which was a zone of mixed rocks in which melting and crystalline flow was dominant. Evidence indicationg porphyroblastic origin for the large microcline megacrysts of the porphyritic facies includes: their presence in country rock inclusions and, locally, country rock marginal to granite; their sieve texture, particularly in regard to fine-grained quartz (fig. 10*A*); and their relatively late appearance in the sequence of feldspar crystallization. The coarse facies in either of the above explanations is interpreted to represent molten core(s?) in which cooling was slow and volatile constituents were partly retained by solidifying outer shells.

GRANITE–COUNTRY ROCK RELATIONSHIPS

Marginal contacts and general trend of the granite of the Romanzof Mountains are concordant with the regional structural trend of the area (fig. 13). The east and northeast trend of the granite mass is roughly parallel to the strikes of large structures, foliation, and, locally, bedding in the adjoining sedimentary and metamorphic rocks. The east margin of the Okpilak batholith, however, truncates units of the Neruokpuk Formation near the Jago River (pl. 1) and the west margin is at least locally crosscutting. The granite does not commonly exhibit definite chilled border zones, although fine-grained granite occurs along some contacts. Foliation and lineation of granite constituents along contacts with Neruokpuk Formation are generally parallel or subparallel to the contact trends. Near contacts with post-Neruokpuk units, features which are interpreted to be primary exhibit a rough parallelism to the contacts in some vicinities; in others they are at wide divergence to the contact trends.

In detail, two markedly different types of contacts characterize the margin of the granite: sharp concordant to crosscutting contacts with or without contact metamorphic aureoles, and gradational contact zones in which porphyritic-facies granite grades into shistose country rock. The first type of contact is mainly restricted to areas in which the granite adjoins rocks of the Neruokpuk Formation but also involves carbonate rocks of uncertain affinity; the second type mostly adjoins the Kekiktuk Conglomerate but also quartzitic rocks ascribed to the Neruokpuk Formation along the northeast margin of the batholith. In addition, zones of shear and contortion between granite and country rock, such as those on the south side of the pluton (see p. 65), may coincide with major thrust faults.

ABRUPT CONTACTS WITH COUNTRY ROCKS

Abrupt contacts of granite with country rock include:

1. Concordant and discordant tonguelike projections of granite as much as several tens of feet thick, which project as much as 100 feet into quartzitic, argillaceous, or carbonate country rock (fig. 14*A*).
2. Irregular granite apophyses, in which angular broken and displaced inclusions of quartzitic country rock are embedded. On an outcrop scale of 50 square feet, country rock fragments have been displaced and rotated only short distances and can be figuratively restored as part of the existing wallrock (fig. 14*B*).
3. Smaller scale infiltration of granite along fractures in quartzites with little displacement of country rock (fig. 14*C*).

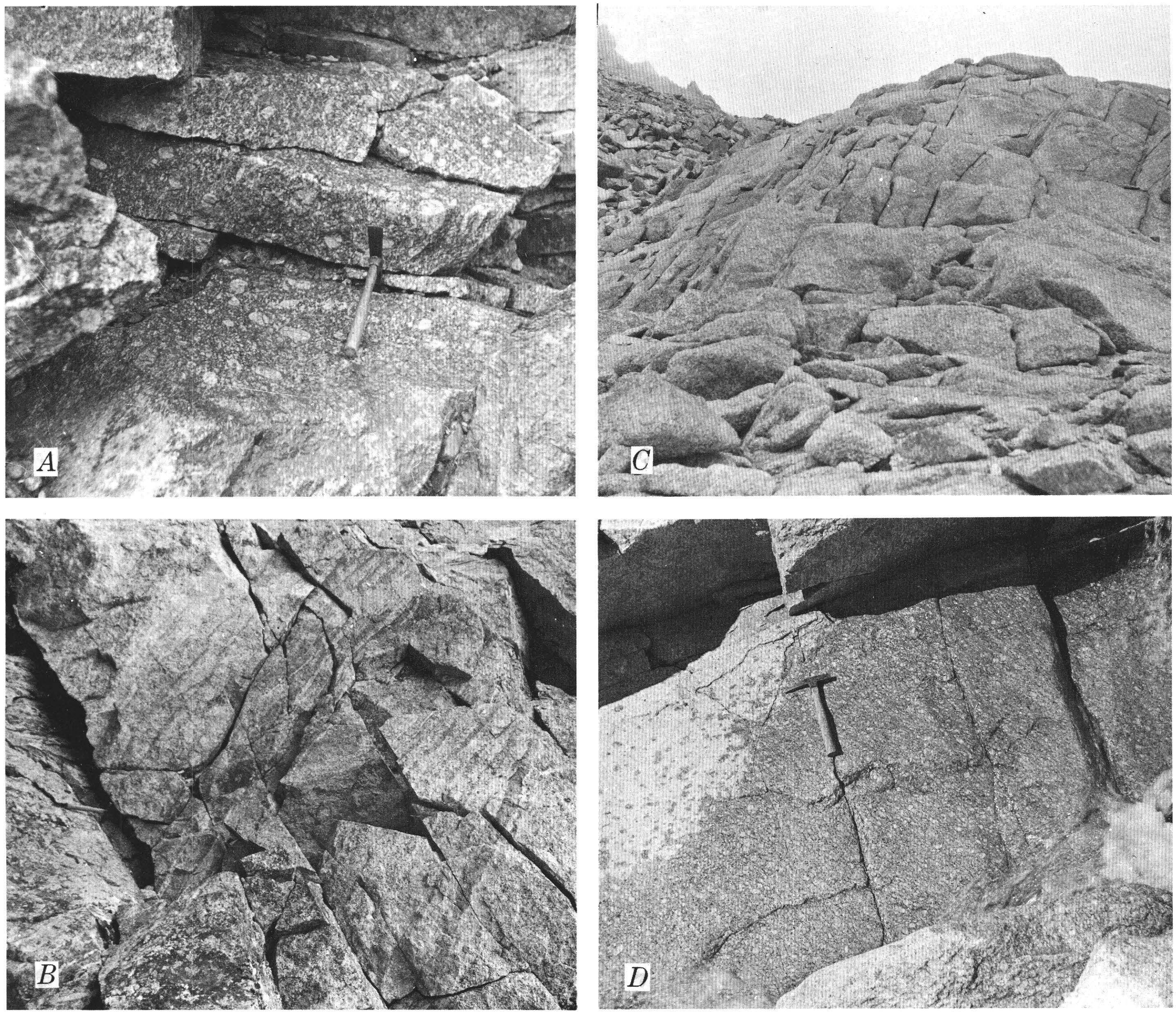


FIGURE 12.—Textural facies in granite of Okpilak batholith *A*, Porphyritic facies, showing lineation of microcline megacrysts. Biotite foliation (not visible) dips toward observer. Leffingwell Creek. *B*, Variable facies, showing mineralogical banding. East side Okpilak River. *C*, Coarse facies lacking in foliation. McCall Glacier, east cirque. *D*, Coarse "gneissoid" facies; feldspar foliation trends from upper left to lower right. Okpilak River, near forks.

4. Concordant, planar to gently curving contacts which can be traced for many hundreds of feet. Sheared rocks commonly adjoin these, and they may represent zones of movement during or after emplacement of the marginal granite.

Features of contact types 1 to 3 clearly indicate intrusive relationships. The mechanisms of assimilation and stoping, at least on outcrop scale, are suggested by the sharp contacts of relatively undistrubed strata on either side of granite apophyses and rounded inclusions in granite. Small-scale forceful injection is indicated also by the local displacement and deformation of country rock at some contacts and by penetration of granite into minute fractures. Structural elements within the granite and regional structural relationships are interpreted to represent forceful injection as the dominant emplacement mechanism.

Contact action of the granite has locally resulted in tactites from impure limestone and in hornfels from pelitic rocks. The changes in granite-quartzite contact rocks are less striking.

Calc-silicate rocks and hornfels are locally present along the west and east sides of the Okpilak batholith; several hundred feet overlie the granite along Hubley Creek in the Jago River drainage, and they are common south of Esetuk Glacier in Hulahula River drainages. In outcrop

FIGURE 13.—Oblique photograph of west fork of Okpilak River looking west. Concordant contact between granite (gr) and Neruokpuk Formation (pMp€n) in foreground. Schistosity and bedding in the metasedimentary rocks dip south for many miles. Terminus of Okpilak Glacier at left side. Photograph by U.S. Navy.

they are mostly aphanitic, dense, dark greenish gray weathering, and highly iron stained with some mineral banding. Along the Jago River, the rocks consist of epidote-amphibolites in which the dominant minerals are tremolite-actinolite, cordierite, and epidote, and the accessory minerals are quartz, vesuvianite, sphene, calcite, apatite, and disseminated pyrrhotite and pyrite. Most of these rocks are a very fine grained mixture with thin bands of tremolite-actinolite-cordierite and tremolite-actinolite-epidote-cordierite. A few hundred feet from the contact near the Jago River, dark rocks within the granite represent altered clastic country rock. They are composed of tremolite-actinolite (35 percent), albite (35 percent), biotite (10 percent), quartz (10 percent), and microcline (10 percent), and abundant accessory sphene and apatite, pyrite, magnetite-ilmenite, and tourmaline. Chlorite and sericite are the chief alteration products. These contact rocks along the Jago River belong to the albite-epidote hornfels facies (Fyfe and others, 1958, p. 201–203).

In the headwaters of the Okpilak River, granite intrudes Neruokpuk quartzites with sharp contact relationships. There the granite contains its usual quartz-microcline-plagioclase assemblage, minor amounts of hornblende associated with biotite, accessory calcite and sphene, and locally abundant apatite. The country rock, to a few feet from the contact, contains corresponding felsic and mafic minerals and relatively abundant sphene, as well as epidote and minor andalusite. The minerals represent the quartzo-feldspathic assemblage of the horneblende hornfels facies (Fyfe and others, 1958, p. 207).

Thermally metamorphosed contact rocks along Esetuk Glacier are at least 80 feet thick and occur in complex synclinal infolds in the granite. Country rock consists mostly of sandy, ferruginous limestone with minor interbedded phyllite. Thermal metamorphism is complicated by introduction of sulfides and magnetite which form small masses. Contacts and contact metamorphic rocks along a traverse in this area are described in measured section 11. Briefly summarized, thermally metamorphosed rocks there consist of epidote-amphibolite hornfels containing tremolite-actinolite, epidote, clinozoisite(?) and quartz, and hedenbergite-grossularite-quartz-cordierite rock. They represent calcareous assemblages and are interpreted to reflect the albite-epidote-amphibolite facies and hornblende-hornfels facies (Fyfe and others, 1958, p. 210–211).

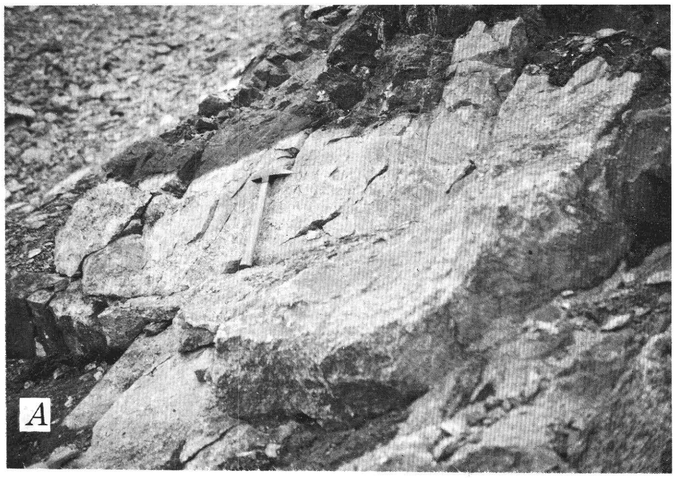
GRADATIONAL CONTACTS WITH COUNTRY ROCK

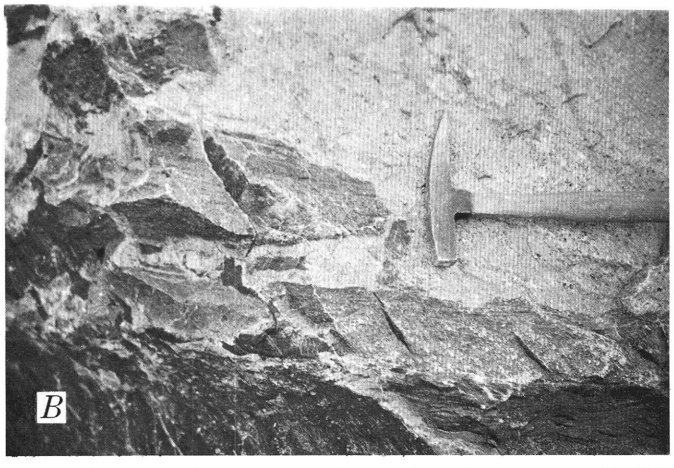
The gradational contact zone between porphyritic granite and overlying quartzites ascribed to the Kekiktuk Conglomerate is well exposed along the northern limit of the granite along the east side of the Okpilak River valley and along the east wall of the Jago River valley. There, about 50–130 feet of quartz-sericite-chlorite schistose rocks which contain fresh to highly altered microcline megacrysts in the lower part and quartz megacrysts throughout occurs between unmistakable granite and overlying nearly horizontal Kekiktuk schistose quartzites. Moderately to steeply dipping biotite foliation in the underlying granite parallels schistosity in the overlying rocks.

Units across this zone along the Okpilak River valley are described in measured section 12. In general, a typical successively upward gradation is (1) schistose granite with quartz-sericite-chlorite groundmass, microcline megacrysts, and ragged patches of chlorite and (or) muscovite with abundant inclusions, into (2) sericite-chlorite-quartz schist with quartz megacrysts and chlorite-muscovite patches, into (3) schistose quartzite with inclusion-filled chlorite patches. Inclusions in the micaceous minerals closely resemble those in the biotite of the fresh granite and include magnetite, apatite, sphene, and garnet.

Proper interpretation of the schistose gradational contacts with the Kekiktuk Conglomerate is important in ascribing an upper age limit to the granite inasmuch as the granite clearly intruded the Neruokpuk but is not known with certainty to have intruded or altered post-Kekiktuk rocks. The inclusion-filled mica and chlorite in Kekiktuk rocks of the contact zone suggest that they are replacements of biotite like that in the granite. The biotite may have been either the product of metamorphism of the Kekiktuk or detrital biotite derived from the granite by erosion. The general lack of biotite in the Kekiktuk in this area and in the Lake Peters area (Reed, 1968, p. 29–31) suggests that the biotite near the granite is metamorphic in origin. The transitional schistose contact zones thus would seem to be associated with granite emplacement or with a later reheating in the vicinity of the pluton.

If both the transitional and pyrometasomatic contact rocks were the results of granite emplacement, these different contact rocks seem to be related not only to the compositional differences of the wallrocks but also to the textural facies of the granite adjoining them. Most of the definite contact-metamorphic rocks adjoin the variable-textured facies, and most transitional contact rocks adjoin porphyritic facies. High viscosity and low temperatures of a porphyritic facies melt during its final emplacement, or the possibility that the porphyritic facies is the product of a "granitizing" metasomatic process might explain the scarcity of pyrometasomatic rocks adjoining porphyritic facies granite. Further discussion relating to apparent contact effects relating to the age of the granitic rocks is given on p. 58.





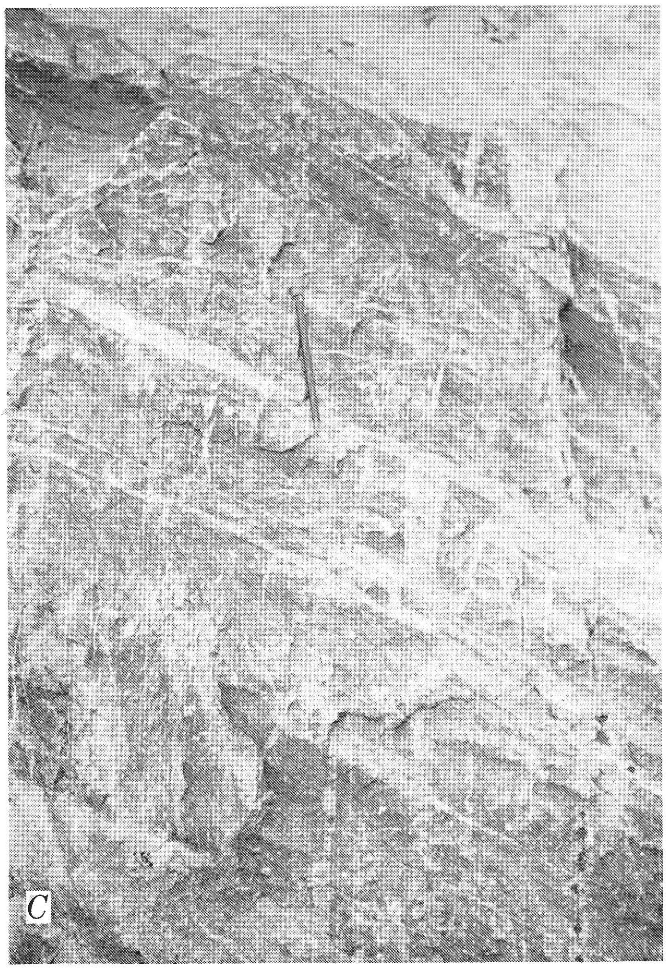


FIGURE 14.—Intrusive contact relationships of granite of Okpilak batholith with country rocks. *A*, Concordant and discordant contacts. West wall of Esetuk Glacier. *B*, Fragmentation of quartzite by infiltration of granite. Boulder, Arey Creek. *C*, Infiltration of granite along fractures in quartzite. Boulder, Arey Creek.

STRUCTURAL ELEMENTS IN GRANITIC ROCKS

The Okpilak batholith and the Jago stock are parts of the same pluton separated in outcrop by a complex overturned synclinal infold. The granitic bodies apparently are synorogenic in that their gross trends and older structural features generally parallel those of enclosing rocks.

The following planar and linear directional elements occur in the granite of the Romanzof Mountains. They are listed in a generally chronological sequence of development, although some features overlap and the positioning of others is uncertain. The term "foliation" as used here refers to planar parallelism of biotite and (or) feldspars in the granitic rocks. Schistosity refers to planar parallelism of micaceous minerals, principally sericite and chlorite, in the metasedimentary rocks or altered granite.

Primary structural elements are:

1. Zones of alternating fine- to coarse-grained granite (rare to common).
2. Biotite schlieren and bands of alternating light and dark (biotite-rich) granite (rare).
3. Elongate inclusions of quartzitic and schistose rock (rare).
4. Zones of migmatite or lit-par-lit rock (rare).
5. Zones of included metasedimentary(?) schistose rock (abundance uncertain).

Probable primary structural elements are:

6. Parallel biotite foliation and feldspar foliation (gneissoid granite) (common to rare).
7. Foliation and lineation of feldspars, chiefly microcline (common to rare).

Structural elements of the late stage of consolidation and postconsolidation deformation:

8. Aplite and pegmatite dikes (aplite rare to common; pegmatite very rare).
9. Bands of tourmaline-impregnated granite (locally common).
10. Fractures filled with quartz and tourmaline (locally common).
11. Dikes of mafic rocks and quartz monzonite.
12. Foliation of biotite (common).
13. Zones of gneissic granite (common in some areas).
14. Zones of schistose granite (common to rare).
15. Streaking of mineral constituents along planes of foliation and schistosity (local).
16. Fractures filled with quartz (common).
17. Fractures filled with chlorite or coarse quartz and chlorite (rare to common).
18. Faults, sheared zones, and cataclastic effects with or without associated zones of sulfides and silicification (common).
19. Joints and fractures (abundant).

CORRELATION OF STRUCTURAL ELEMENTS

To determine whether the many structural elements could be correlated with a few major stages of deformation, the trends of all the directional elements measured in the field, as well as various linears seen on aerial photographs, were compared. The attitudes of most of these structural elements are shown in figures 15, 16, and 17, and on plate 2. Trends of some directional elements, such as joints, biotite foliation, and linears seen on aerial photographs, can be correlated over wide areas. For other elements, such as textural differences and feldspar foliation, the correlations are inconclusive. Attempts to relate different joint sets to foliation in isolated localities by stereographic projection methods were unsuccessful.

Trends of textural zones, compositional and textural banding, and alinement of inclusions (pl. 4) are consistent with my assumption that these are primary features of the granite. However, in some parts of the pluton, foliation attitudes do not coincide with the compositional and textural banding, as shown by the following examples. In granite gneiss that crops out in the cirque wall of a hanging glacier tributary to Leffingwell Glacier, parallel feldspar and biotite foliations strike N. 70° E. and dip 57° SE., and are crossed by biotite schlieren at E. strike, 60° S. dip. At a locality along Esetuk Glacier, feldspar foliation strikes N. 85° W., and dips 80° SW., and a cross texture of faint compositional banding and some feldspars strikes N. 85° E., and dips 45° SE. Along the lower part of Leffingwell Creek, biotite foliation strikes N. 85° E., and dips 70° SE., and many microcline megacrysts are oriented parallel to or normal to this direction; bands of concentrated microcline megacrysts with their long axis approximately parallel to biotite foliation, however, strike N. 85° W., and dip 60° NE. Are the primary layers north-dipping and is the south-dipping biotite alinement the result of later stresses? At a nearby locality along Leffingwell Creek, biotite foliation strikes N. 60° E., and dips 80°–85° NW., and subparallel feldspar strikes N. 55° E., and dips 50°–80° NW.; both cross textural banding which strikes N. 60° W., and dips 35° NE. Here, also, primary layering apparently does not coincide well with foliation directions.

The granite exhibits some features that can be interpreted as originating in either a liquid or solid state. As suggested previously, the large microcline megacrysts, for instance, might be porphyroblasts rather than primary phenocrysts. Each part of the area was examined with these possibilities in mind, and interpretations were made on the basis that compositional and textural banding reveal the primary stress orientation. On this basis, most feldspar foliation and combined feldspar-biotite foliation in relatively undeformed granite are interpreted as primary structures due either to flow layers or to orientation by stresses normal to the foliation during emplacement of the granite. Biotite foliation without parallel feldspar is interpreted to be a result of deformation of the granite after emplacement and either before or after final consolidation.

Textures and structures that are interpreted to reflect primary features, a combination of primary and secondary features, and deformation of solid granite are illustrated respectively in figures 12, 18, and 19.

FOLIATION OF FELDSPAR AND BIOTITE

Foliation of feldspar and biotite ranges from conspicuous to indistinguishable. In many parts of the area, feldspar foliation coincides approximately with trends of primary features. Biotite foliation is normally very pronounced (fig. 20), but commonly it strikes at acute or even right angles to the feldspars and to primary features such as rows of inclusions and banding. In some localities, biotite and feldspar foliations in apparently undeformed granite coincide or are subparallel, lie along well-developed joints, and are interpreted to represent primary features. In many places, however, gneissic textures with streaking of minerals, fine-grained granular quartz, and a high degree of fracturing and augen texture of feldspars indicate realinement by dynamic metamorphism after consolidation. Extensive alteration of biotite to chlorite in these exposures may indicate retrograde metamorphism accompanying this deformation. Textures intermediate between these extremes occur in large areas of the granite pluton, making interpretation of foliation significance difficult. They indicate, however, that the pluton has been subjected to intense deformational stresses during late- or post-consolidation stages.

Feldspar foliation (fig. 16) is mostly steeply dipping to vertical, and in most of the area the dominant dip component of foliation and lineation appears to be southerly, although in the southeastern and southern parts of the Okpilak batholith northerly dips are probably dominant. Analysis of feldspar foliation indicates that it more closely coincides with wallrock contacts and with the few recognizable primary features than does biotite foliation. The lack of foliation readings in some of the area covered by fieldwork indicates areas of schistose and gneissic granite or, in the McCall Glacier vicinity and east, areas where foliation is lacking.

Biotite foliation is shown in figure 17. In the northern part of the Okpilak batholith it strikes east-northeast and dips south. Farther south, attitudes and trends are more variable, but still with a dominant southerly dip component. Dips are boderate to steep. Biotite foliation probably is not an indication of primary structural features in the granite, because (1) it closely coincides with schistosity and gneissic foliation in deformed granite, (2) it crosses some aplite dikes, (3) it parallels orientations of individual inclusions but not rows of inclusions, and (4) it parallels slaty cleavage in the Mississippian through Jurassic sedimentary rocks north of the batholith which from several lines of evidence, seem to be younger than the granite. Biotite foliation and slaty cleavage may nevertheless reflect a stress field imposed on a nearly or wholly concolidated outer shell of the pluton during the late stages of emplacement; if so, the granite would postdate the Jurassic rocks of the area. Biotite foliation, once established however, might have provided a preferred directional control for later cataclastic effects and schistosity.

SCHISTOSITY AND SCHISTOSE ZONES

Features ascribed to postconsolidation deformation within the granite, which may or may not be related to granite emplacement but which appear to be interrelated, are schistosity, gneissic foliation, linear schistose zones, and some joints, all shown on plate 2, in addition to faults and possibly biotite foliation, already discussed.

Schistosity in the granitic rocks, largely the result of parallelism of sericite and chlorite, seems to occur in irregular broad areas, the trends and limits of which are not well understood. With increase in unaltered feldspar content, schistosity seems to grade into gneissic foliation, which also occurs in broad ill-defined areas. Linear schistose zones which occur along well-defined trends, however, contain schistose and gneissic rocks.

In the northern one-third of the Okpilak batholith, schistosity, gneissic foliation, and biotite foliation are generally parallel, striking N. 60°–80° E. and dipping moderately to steeply south. In the south-central and eastern parts of the batholith and in the Jago stock, this relationship is not as consistent, and there biotite and feldspar foliation, at least locally, are more closely related in attitude, perhaps an indication that the biotite foliation reflects primary structure there. In the eastern part of the batholith and in the Jago stock, the schistosity and gneissic foliation generally strike northeast, but in the headwaters of the Okpilak River they have diverse trends.

Linear zones of sheared schistose granite from a few feet to tens of feet wide are common in some parts of the area (fig. 21). In these, granitic constituents have been broken, rotated, and recrystallized to chloritic and sericitic schistose granitic rock. Their attitudes (pl. 2) generally do not correspond to those of the schistosity and gneissic structure described in the preceding paragraph. Many of the linear zones strike nearly north and seem related to the north-striking pattern of prominent joints and faults observed north of the granite. Relationships of these zones to the schistosity and gneissic foliation already described is obscure; schistosity in most of the linear zones is parallel to their attitudes, but in some vicinities schistosity crosses the linear zones of schistose granite. An example is a N. 30° W.-striking zone near the northern front of the granite in the Okpilak River valley, where schistosity in the zone and biotite foliation in the adjacent granite strike N. 80° E.

The mineralogy of rocks in some schistose zones indicates alteration of original granite constituents to chlorite and sericite, as well as the introduction of sulfides, fluorite, and tourmaline. The presence of tourmaline, the transverse schistosity across some zones, and the fact that some zones are subparallel to primary features suggest that these are shear zones which closely followed granite emplacement, and that they mark planes of weakness which controlled later dislocations. The shear effects probably extended to considerable depth with the result that the original granite constituents were partially to wholly altered by the addition of volatiles (mostly water), iron, and magnesium. Biotite and feldspars were altered to mixtures of chlorite and sericite, microcline megacrysts were converted to flattened relicts of sericite-chlorite (fig. 8*B*), and quartz was granulated and possibly in part recrystallized to quartz megacrysts.

DIKES

Four kinds of dike rocks in the Romanzof Mountains are aplite, pegmatite, quartz monzonite, and aphanitic mafic rocks. Locations and trends of individual dikes are shown on plates 1 and 4.

APLITE AND PEGMATITE

Aplite dikes are common and seem to be most abundant

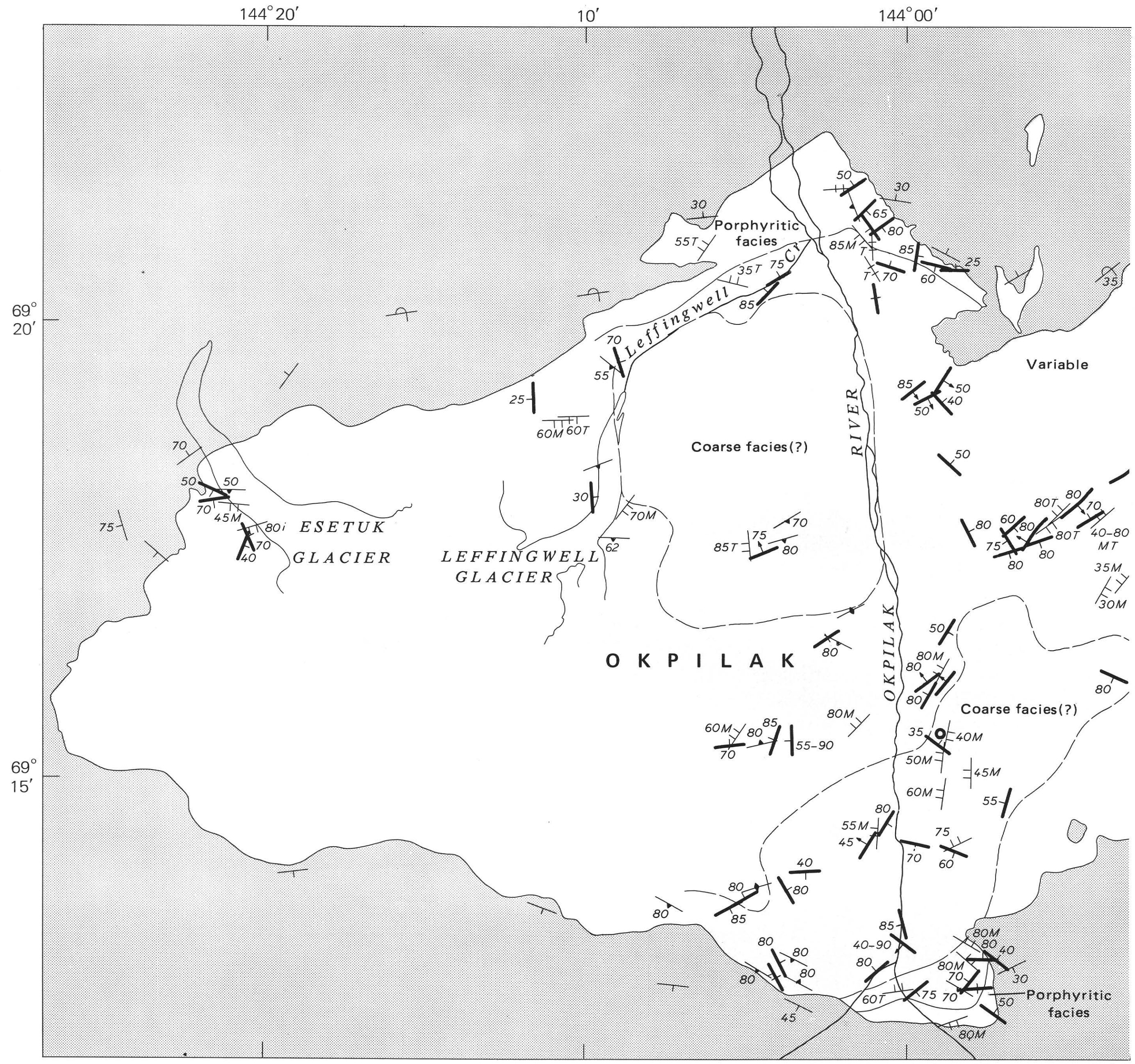
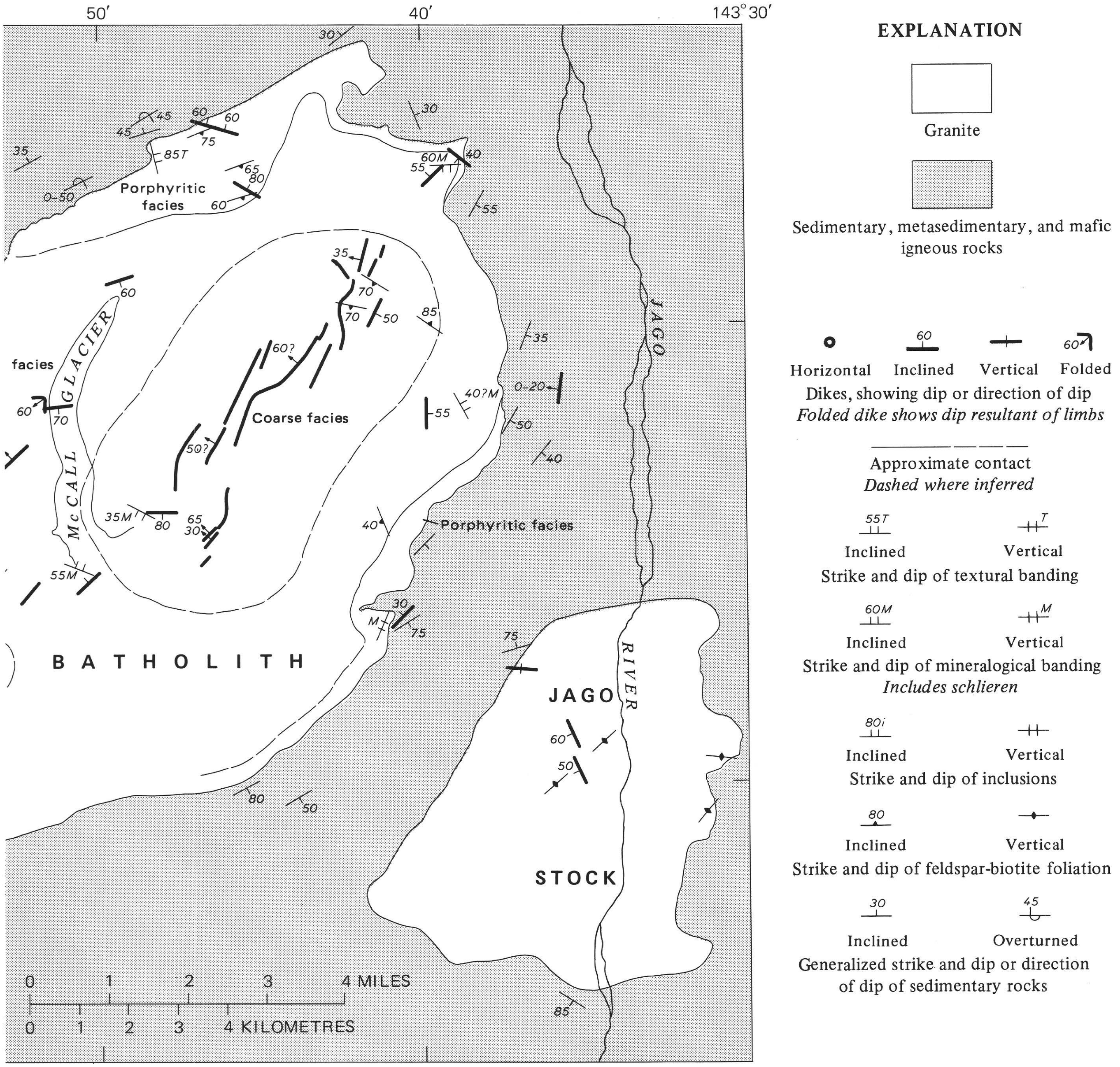


FIGURE 15.—Attitudes and trends of primary features in granite, dikes in granite and

in the variable and porphyritic facies of the granite. They crosscut all essential granite minerals including feldspar megacrysts and inclusions of country rock. They are commonly planar but locally they are curved and appear to be folded, suggesting that some were plastic during emplecement. Their mineralogy corresponds to that in the adjoining granite, and some contain tourmaline, pyrite, and fluorite. Although the dikes are crosscutting, biotite foliation where recognizable within the dikes parallels biotite foliation in the surrounding granite. A few aplitic dikes occur in quartzites of the Neruokpuk Formation along the southern margin of the Okpilak batholith, but none were seen in younger rocks.

Most of the aplite dikes, as indicated by 72 attitude readings, dip more steeply than 50°. The diverse orientations of the dikes do not indicate an overall simple fracture pattern related to emplacement of the pluton. Instead, several obscure patterns seem to be present, perhaps the result of stresses directed from the areas of coarse facies granite. Locally, however, inward-dipping dikes along some margins of the pluton may represent filled marginal fractures (Balk, 1937, p. 101–103). Many dikes within the



intruded rock, and bedding of sedimentary rocks, Romanzof Mountains, Alaska.

pluton also locally correspond to trends of feldspar foliation and primary features and may represent filled longitudinal joints (Balk, 1937, p. 34–36).

The pegmatite dikes are not abundant and are of simple composition: feldspar (70 percent), quartz (25 percent), locally biotite or chlorite (5 percent), and accessory tourmaline and fluorite as small aggregates. Few pegmatites that exhibit sharp crosscutting relationships were seen; most of them show irregular gradational relationships with adjoining granite. No foliation was noted in pegmatites, and no relationships with schistose zones were seen in the exposures examined. Distribution of pegmatites relative to granite textural facies is not known.

QUARTZ MONZONITE

Two compositional varieties of dark rocks in steeply dipping tabular bodies are present in the Okpilak batholith—the dark-gray porphyritic quartz monzonites, discussed here, and green aphanitic mafic rocks, discussed on page 60. Both occur in the variable and coarse facies and possibly in the porphyritic facies, but their interrelationships are not known.

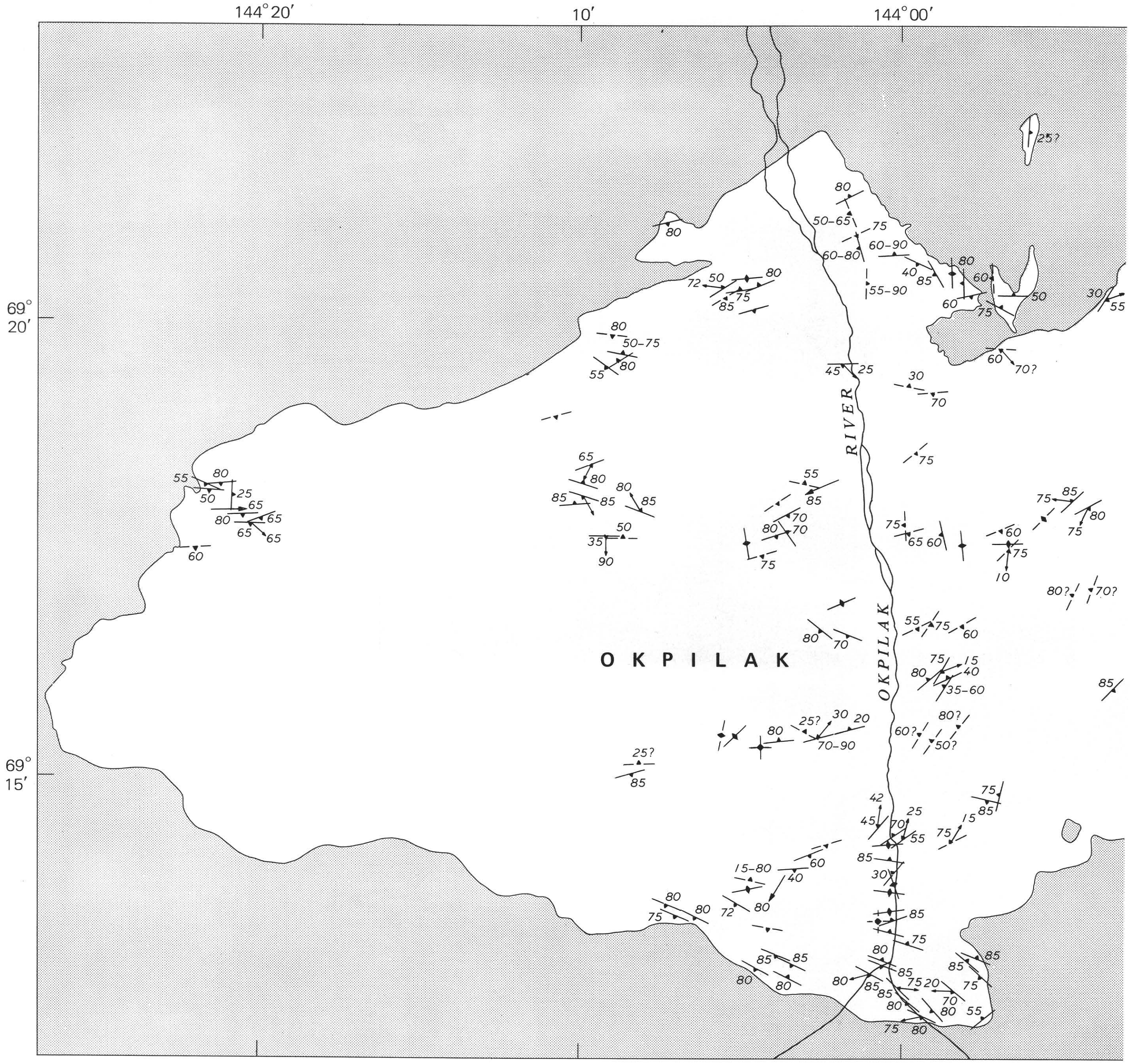
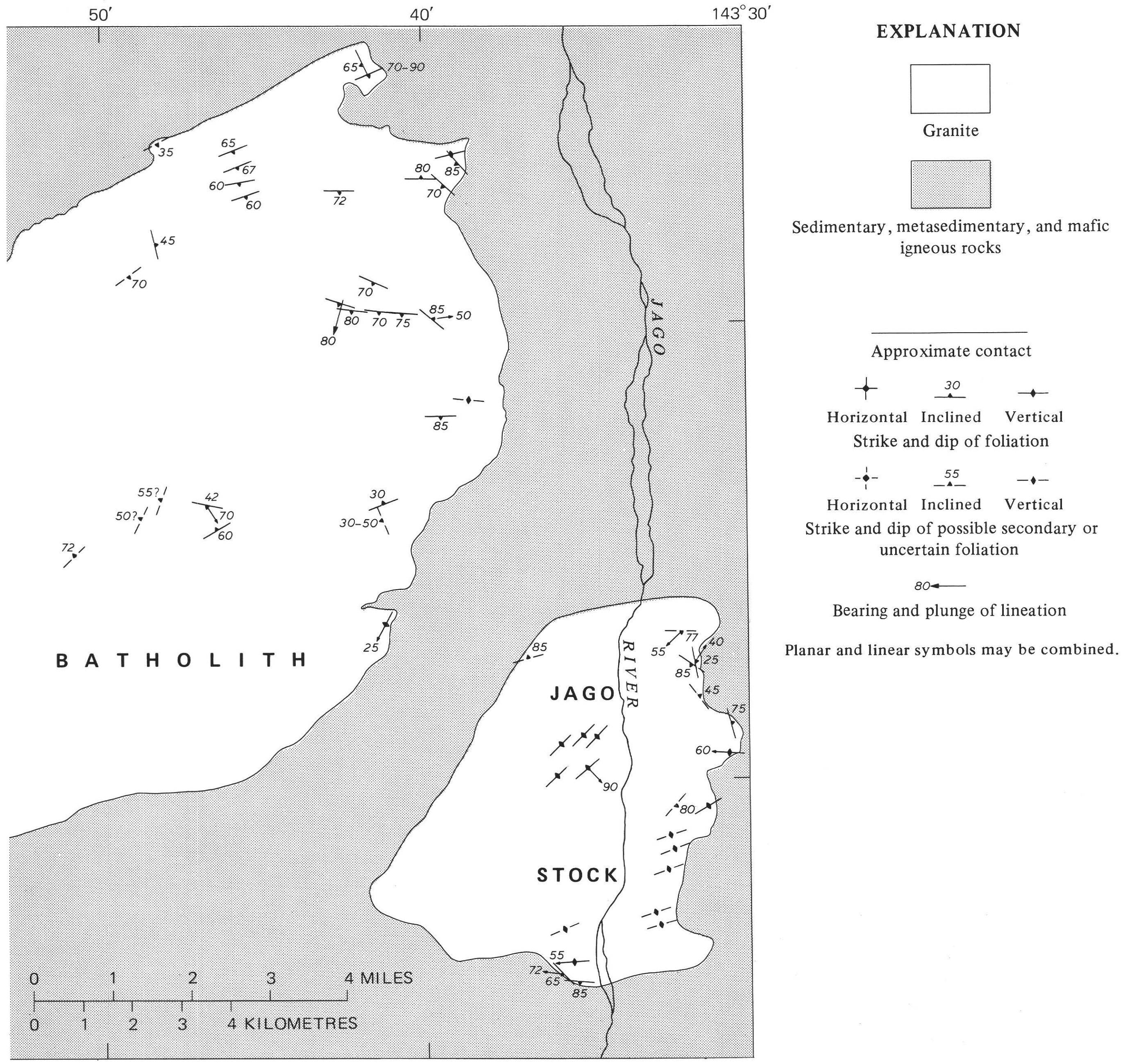


FIGURE 16.—Feldspar foliation and lineation

The quartz monzonites were seen in a single belt of northeast-striking dikes between Okpilak River and McCall Glacier. They dip steeply northwest and individually are as much as 300 feet thick. Where seen, their contacts with granite were sheared. Abundant float of these dark rocks was also seen west of the Okpilak River, as in the northernmost medial moraine of Leffingwell Glacier. There the morainal material can be traced on aerial photographs into a dark west-trending belt. Similar belts of dark-appearing rocks in the Okpilak batholith trend west-northwest south of Mount Michelson (pl. 1), and it is speculated that they contain dark quartz-monzonite or mafic bodies.

The quartz monzonites are characterized by abundant euhedral to ovoid perthitic microcline megacrysts which contrast with the dark-gray aphanitic groundmass. The megacrysts commonly show a strong preferred orientation parallel to the steeply dipping dike sides (fig. 22). Smaller plagioclase (about An_8) and quartz megacrysts and biotite aggregates are also essential constituents. The biotite appears to be pseudomorphous after hornblende. A microgranular intergrowth of the above minerals consti-



in granite, Romanzof Mountains, Alaska.

tutes the graoundmass, with quartz making up about 80 percent. Quartz-calcite veins cut the microcline megacrysts, and sericite occurs along some vein margins.

Some small irregular areas of dark porphyritic rock, compositionally and texturally similar to the tabular bodies, occur in and are gradational with leucocratic granitic rocks. Features that are interpreted to represent primary structures roughly parallel those in the enclosing granite. The dark quartz monzonites are considered to be essentially cogenetic with the main mass of granitic rocks.

VEINS AND REPLACEMENTS

TOURMALINE OCCURRENCES

Black tourmaline (schorlite) is present in all granite facies and is locally abundant. It occurs as replacement of biotite and feldspars; in veins by itself or associated with quartz, pyrite, and fluorite; in greisen; as rosettes; and locally as disseminations in granite. Black vein tourmaline also occurs in the Neruokpuk Formation. Clear gray tourmaline was seen in contact metasomatic rocks along Esetuk Glacier.

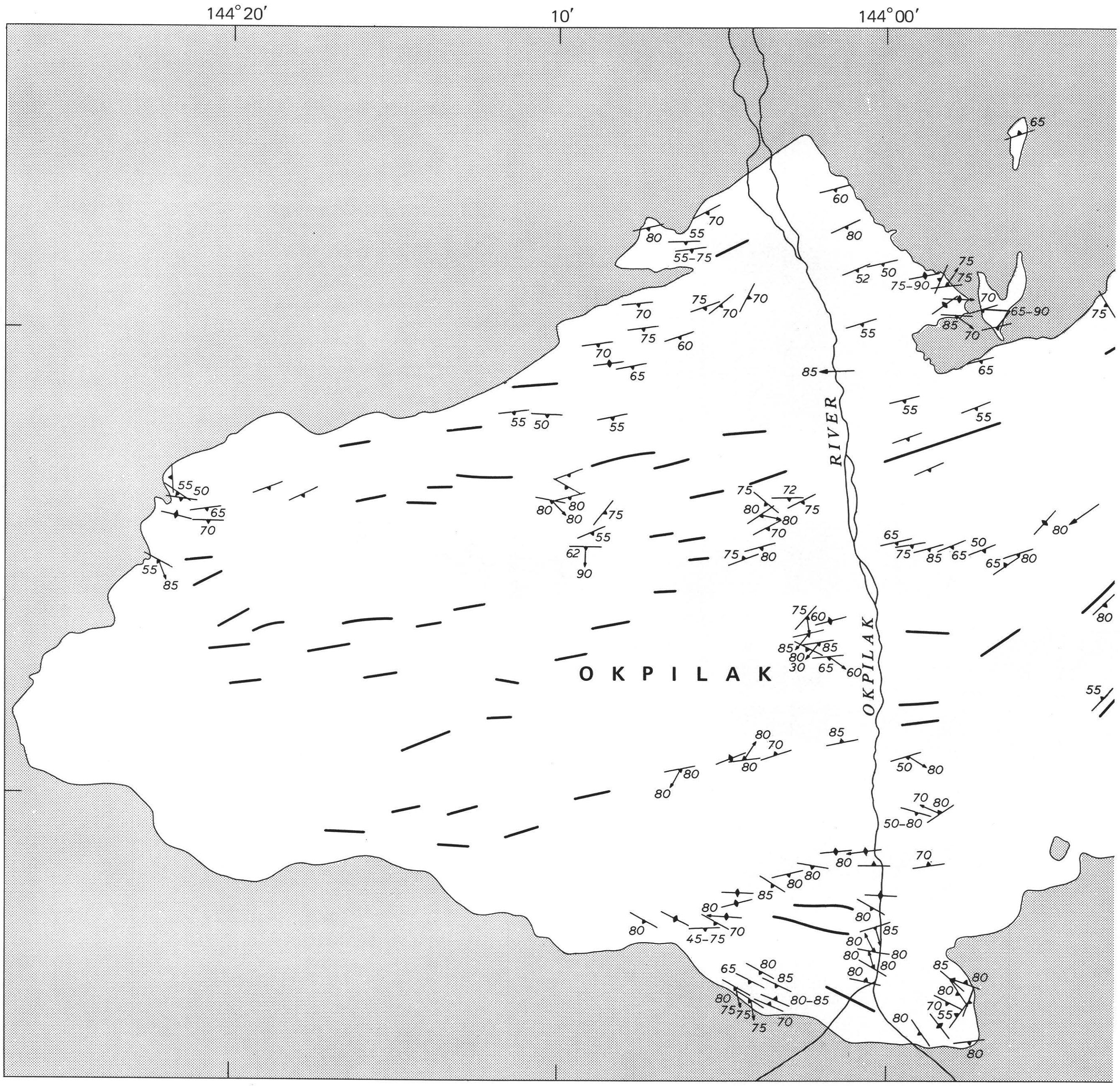


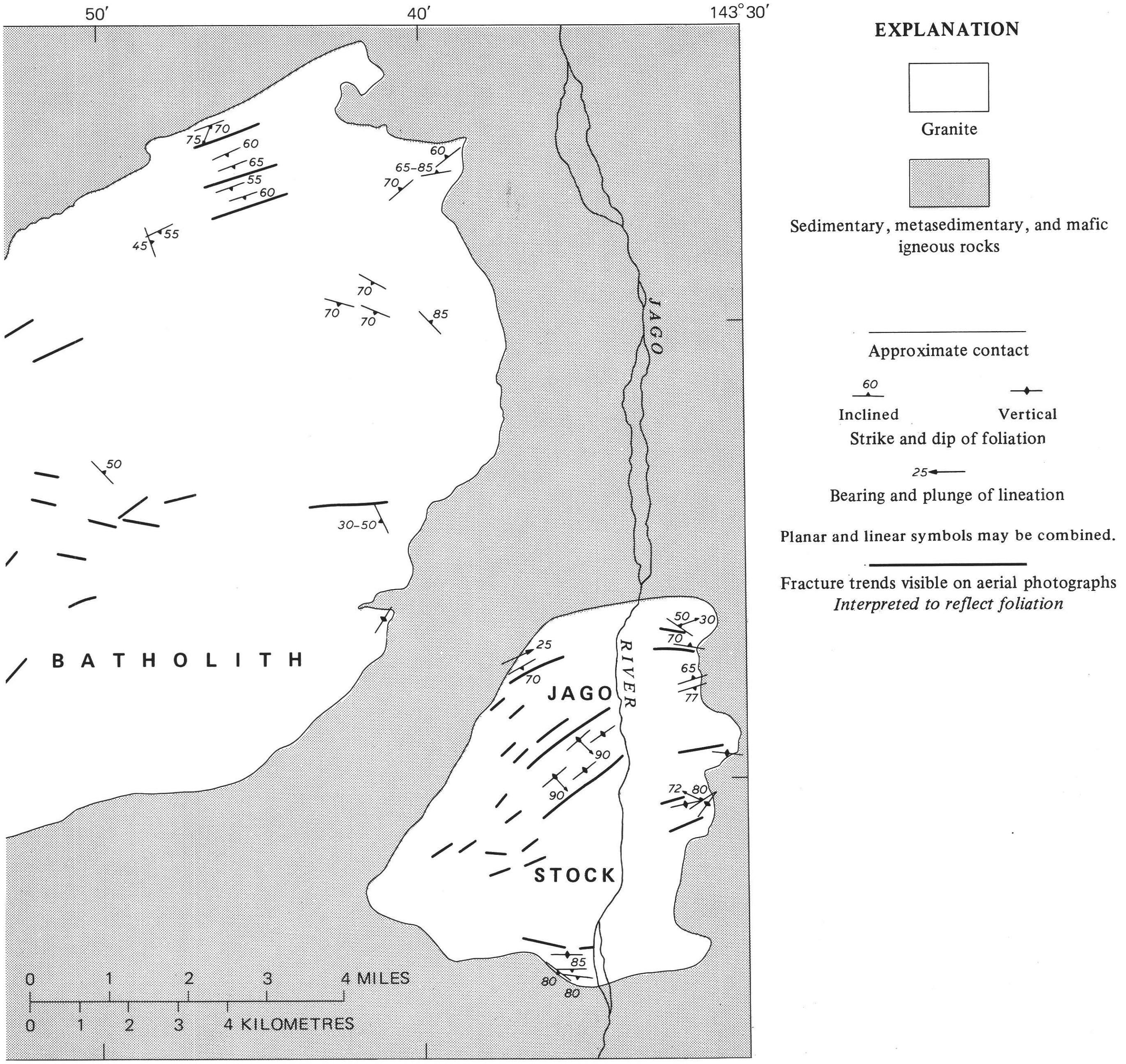
FIGURE 17.—Biotite foliation and lineation

In thin section, schorlite ranges from brownish gray in replacement and vein tourmaline to alternating brown and blue in zoned disseminated crystals; it is strongly pleochroic. In veinlets and concentrated replacement bands, n_{ω} is 1.666 to 1.670 and n_{ϵ} is 1.646 to 1.652; in rosettes, n_{ω} is 1.653 and n_{ϵ} is 1.632.

Tourmaline disseminated in granite is subhedral to anhedral and in many thin sections appears to have been shattered and recemented by quartz. Locally it contains tiny aggregates of sphene(?) and interstitial biotite which it has partially replaced. It also penetrates microcline along cleavage planes. In some tourmaline replacement bands, 2–12 inches wide, all essential granite minerals except quartz have been replaced.

Tourmaline veins are locally abundant. They are less than one-half inch thick and occupy planar fractures; vein boundaries are mostly sharp, and at some localities vein tourmaline is altered to chlorite. Rosettes are particularly abundant in some aplites and in shear zones where muscovite, epidote, fluorite, and sulfides occur, as along the north side of Arey Creek.

About 40 readings on tourmaline vein sets are plotted on



in granite, Romanzof Mountains, Alaska.

the orientation diagrams on plate 2. Most of these tourmaline veins dip at moderate to steep angles and are inward-dipping along the west, northwest, and eastern margins of the Okpilak batholith. In some localities, veins and replacement bands parallel aplite dikes which also contain intergrowths of tourmaline. Some veins, clearly younger than the aplites, also sharply cut these rocks. Some veins are parallel to schistosity in the granite; one such vein crosses biotite foliation, but others locally parallel the biotite foliation. No vein was found that crosses schistosity. No consistent relationship to open-joint sets is evident, although the presence of some north-striking veins along the Okpilak River indicates that the north-trending joints which are now so prominent may have been generally contemporaneous with granite emplacement. It has not been established whether tourmaline veins cut quartz monzonite or mafic dikes in the granite.

Some crosscutting tourmaline replacement bands have perfectly preserved an earlier gneissoid foliation including feldspar megacrysts. Others are parallel to feldspar-biotite foliation. At one locality northwest of Leffingwell Glacier, such a band parallels foliation which strikes N. 65° E. and dips 57° S., and which crosses biotite-rich schlieren that strike east and dip 60° S. There, the time relationships apparently reflect a primary structure and a later gneissoid foliation coincident with or controlling later tourmaline impregnation.

Black tourmaline mineralization occurred as early as the emplacement of aplite and pegmatite but continued after their consolidation. The inward-dipping character of tourmaline veins may be indicative of cross joints as used by Balk (1937).

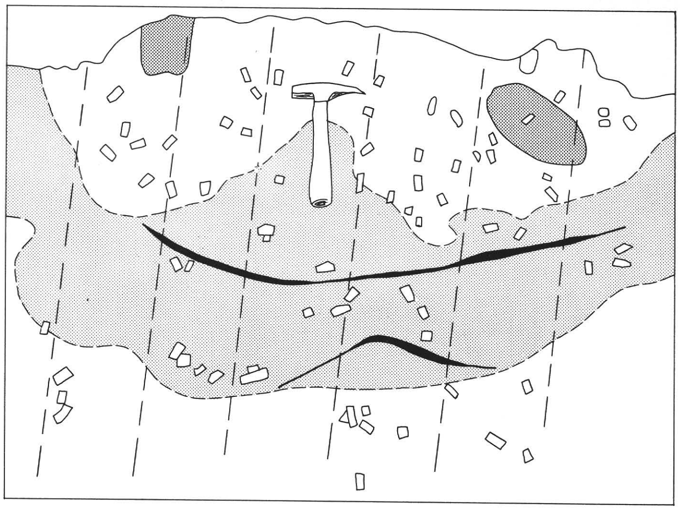


FIGURE 18.—Relationships of primary and secondary features in granite, Okpilak River. Dark bodies in upper part are inclusions (primary); shaded band across center is biotite-rich granite (primary); thin black bands are schlieren (primary?). Small rectangles are microcline megacrysts (primary?); steeply dipping dashed lines represent biotite foliation (secondary), the strike of which is roughly normal to page. From field photograph.

CHLORITE VEINS

Chlorite, quartz-chlorite, and quartz-chlorite-calcite veins are abundant in granite and less abundant in rocks of the Neruokpuk Formation. In hand specimen, vein chlorite is dark grayish green, aphanitic, and locally contains disseminated pyrite. Under the microscope it is a yellowish-green granular microaggregate, different from the flaky aggregates that result from the alteration of biotite. Veins composed wholly of chlorite are most common. They are straight and are mostly less than one-half inch thick. Bleaching effects from alteration of biotite and kaolinization of microcline along the veins extend to 1 inch into the granite. Chlorite of this type also occurs as vein filling between large quartz crystals that line the vein walls.

The chlorite veins in granite belong to a very late stage of mineralization. They cut aplites, quartz and

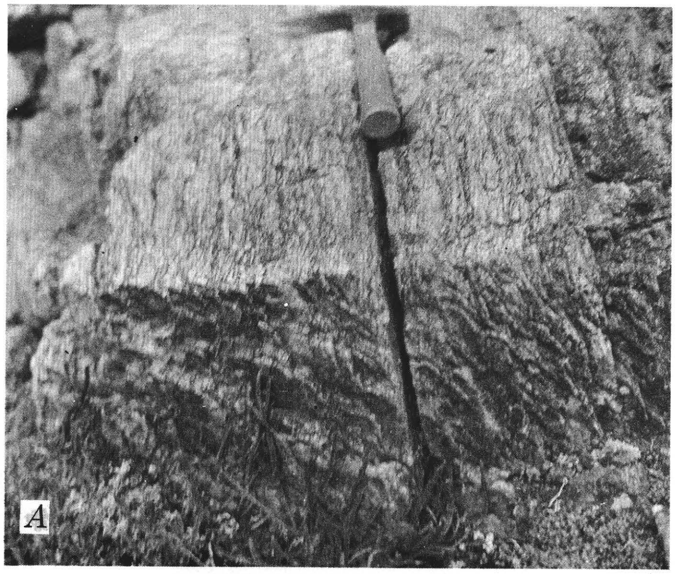


FIGURE 19.—Granite showing strong secondary foliation. Okpilak River. *A*, Gneissic granite. *B*, Schistose granite with fractured microcline megacrysts.

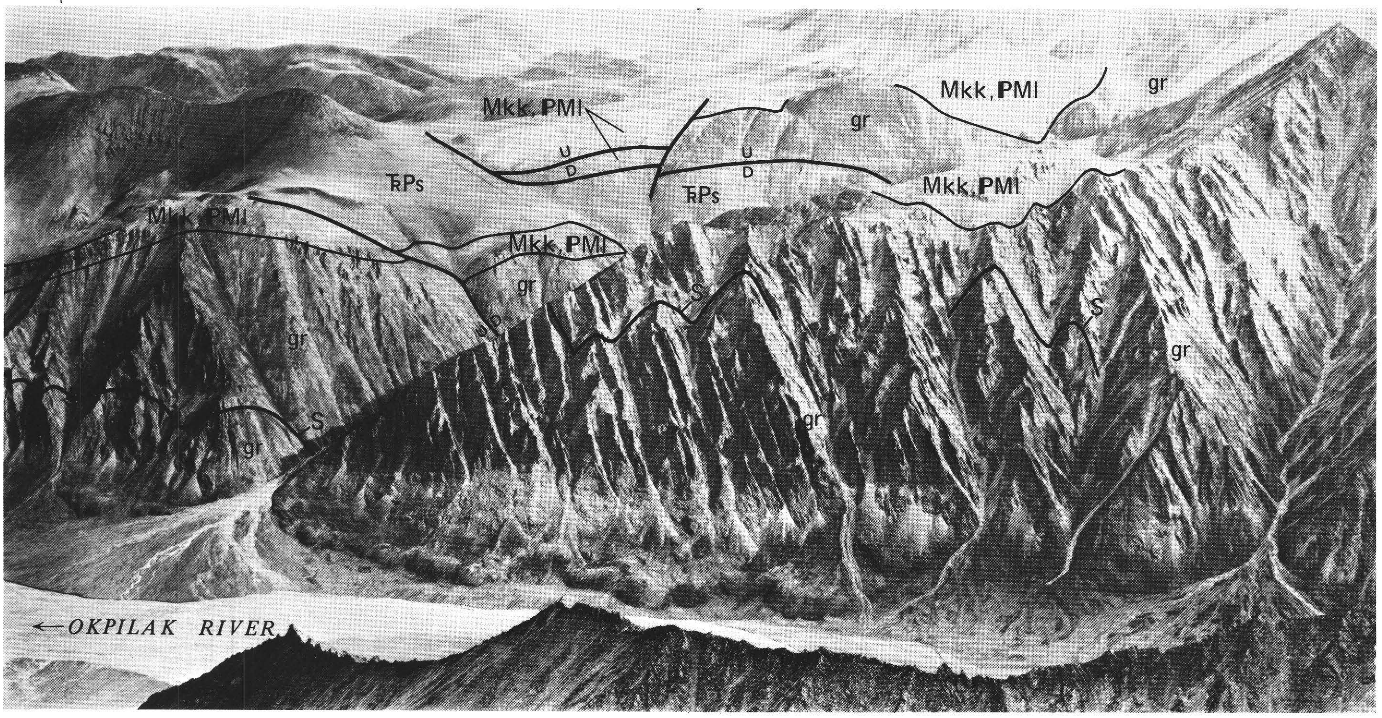


FIGURE 20.—Oblique photograph of Okpilak River valley, looking east. South-dipping fracture pattern on mountainside reflects well-developed biotite foliation and schistosity cut by north-trending steeply dipping faults, shear zones S, and joints. U, upthrown side of fault; D, downthrown side. gr, granite; Mkk, Kayak(?) Shale and Kekiktuk Conglomerate; IPMl, Lisburne Group; TR Ps, Sadlerochit Formation. Fourth advance lateral moraines at base of mountain. Photograph by U.S. Navy.

tourmaline veins, quartz monzonite dikes, and quartz veins. The quartz veins rarely cut chlorite veins. Many chlorite veins are slickensided, and some are displaced a few inches along later fractures. In a few vein localities chlorite of this type is associated with, and appears to be a replacement of, tourmaline. Possibly many of these chlorite veins are complete replacements of tourmaline along selective fracture sets, but some were seen to cross unaltered tourmaline veins at several localities, and these are obviously due to later chlorite introduction. Most of the chlorite veins, as shown by 56 attitude readings (some on pl. 2), strike roughly north and dip steeply to the west. They parallel prominent joints which are interpreted to be extension or longitudinal fractures.

QUARTZ VEINS AND REPLACEMENTS

Vein quartz is common in the granitic rocks and in all pre-Cretaceous clastic rocks in the area. Veins in granite range in width from a few inches to about a foot and are composed of highly fractured clear to milky quartz. Some open veins are lined with colorless and smoky quartz crystals as much as 1 inch in diameter and several inches long. Some crystals show strain features such as planar internal fractures which cross crystal clusters irrespective of individual crystal orientations and which are parallel to planes of schistose foliation in the granite. Other veins of finely crystalline quartz show colloform structure or drusy surfaces and are in some places intergrown with fluorite and pyrite. Quartz-tourmaline, quartz-chlorite, and calcite-quartz associations occur in granite. Tourmaline is intergrown with quartz; granular chlorite fills interstices between large quartz crystals in granite and is interpreted to be later than the quartz, perhaps of the same age as the chlorite veins described in the preceding paragraph.

Attitudes of 58 quartz veins recorded in granite (pl. 2 orientation diagrams) indicate a north-northwest striking and steeply dipping set and other less well defined sets which roughly parallel the long dimension of the batholith. Along the north margin of the granite, many quartz veins with low to moderate dips locally occur in sets which strike roughly parallel to the north margin.

Barren quartz veins in the sedimentary rocks are similar to those in the granite, but many contain argillaceous impurities. Most crystals in open-filling veins show comb structure normal to the vein walls, but some aggregates are inclined as much as 30° from the walls. These seem to indicate crystallization in a shear stress field or during unidirectional high-pressure flow of silica-bearing solution. Calcite veins with some intergrown quartz are common in carbonate rocks; calcite veins and lenses are not common in granite, but several were observed near Leffingwell Creek.

About 60 readings on quartz veins in sedimentary rocks north and east of the granite (pl. 2) indicate strong control by northward-trending steeply dipping fractures. Quartz is particularly abundant in gash veins and stockworks near faults and in the axial areas of minor folds.

At least two stages of quartz introduction are probable in the granite. Some vein quartz is associated with tourmaline. Most vein quartz, clearly predates chlorite veins which are posttourmaline. Open quartz veins with large crystals cross the granite–Kekiktuk Conglomerate contact zone along the Okpilak River. Relationships of quartz-sulfide (mostly pyrite) veins to other filled fractures are not known. Slickensided and striated quartz along faults in granite and sedimentary rocks indicates movement after some quartz introduction, and some veins are displaced at least several feet by hairline faults.

Some tabular bodies of fine-grained quartz with saccharoidal texture, locally containing disseminated pyrite, are interpreted to represent zones of silicification along faults. A striking example of this occurs between McCall Glacier and Arey Creek where as much as 50 feet of gently dipping white to iron-stained quartz rock overlies a zone of highly crushed granite. A similar silicified and brecciated zone lies along a steeply dipping fault between Sadlerochit Formation and granite 5 miles south-southeast of Okpilak Lake.

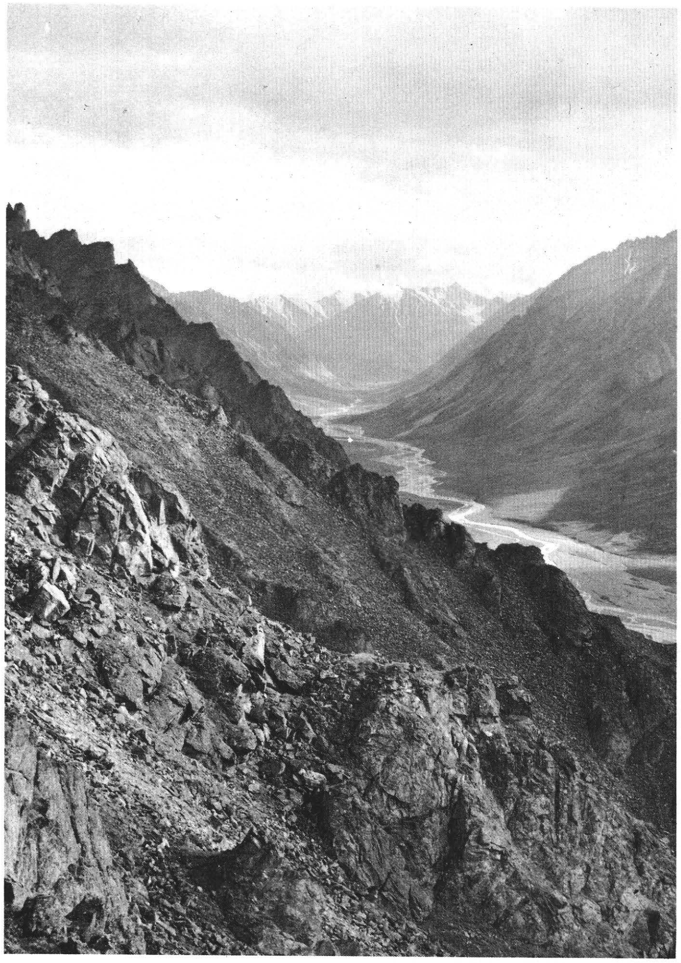


FIGURE 21.—Sheared schistose zones in granite on east wall, Okpilak River valley. Resistant pinnacles of relatively unaltered granite alternate with swales of schistose granite. View southward.

JOINTS

JOINTS NORTH OF OKPILAK BATHOLITH

The attitudes of recorded joints in rocks of the mapped area are shown in equal-area projections on plate 2. Pole maximums in rocks north of the Okpilak batholith indicate well-developed steeply dipping sets of transverse joints which strike north to north-northwest. In subareas I and II, mostly east of the Okpilak River, N. 30° W. and N.

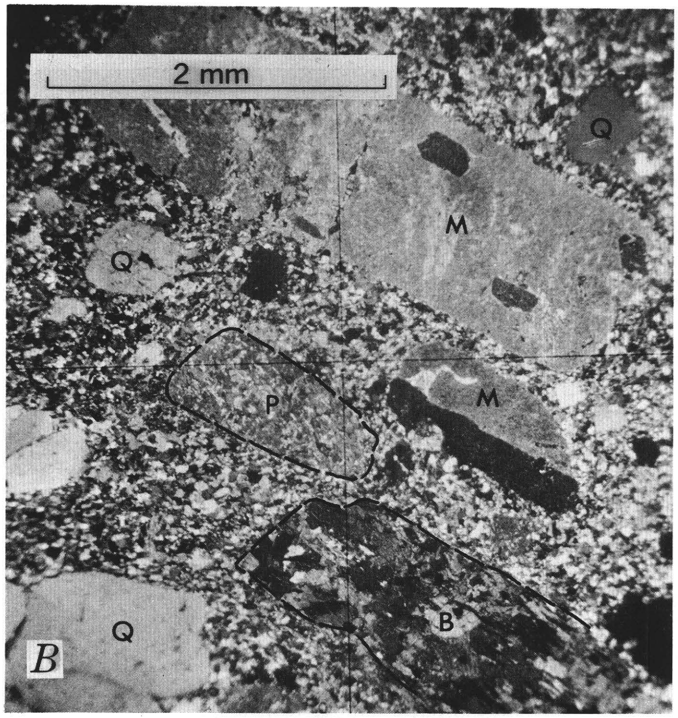


FIGURE 22.—Quartz monzonite porphyry. *A*, Outcrop along tributary of Arey Creek. Lineation of feldspar megacrysts subparallel to hammer handle. *B*, Photomicrograph. M, microcline; P, sericitized plagioclase; B, biotite; Q, quartz. Crossed polars.

0°–10° W. strikes are dominant. The N. 30° W. set is normal to prevailing rock cleavage and fold axes, and both sets are parallel to trends of transverse faults (pl. 1). In subareas III and IV, west of the Okpilak River, N. 30°–45° W. strikes are conspicuous and generally parallel the transverse fault pattern. Less prominent east-northeast striking, steeply to moderately dipping joint sets in subareas I–IV form a conjugate system with the north-northwest sets. Most quartz veins are parallel to this system; others have much lower dips.

The N. 30°–45° W. joints are interpreted to represent extension fractures formed contemporaneously with the latest orogeny. Slickensided surfaces along some of the joints show evidence of small displacements; this, and their general parallelism to the transverse fault pattern (plate 1) suggest that they may have predated these faults and controlled their trends.

JOINTS IN OKPILAK BATHOLITH AND ADJOINING AREAS

Joint patterns in the granitic rocks of the Okpilak batholith and adjoining Neruokpuk Formation areas are represented by more than 500 readings (pl. 2). Three to four sets of joints are commonly present at most localities in the granite. The contour patterns show more random distribution of pole maximums in these rocks than in rocks north of the batholith and indicate several moderately to steeply dipping joint sets. The steeply dipping north-and northwest-striking sets which are conspicuous north of the batholith are present here also, but the northwest-striking set has a more shallow westerly dip component than in the sedimentary rocks.

In subareas V–VII and IX (pl. 2) four major joint sets are present:

1. Joints that strike N. 30°–45° W. and dip vertically and moderately steeply west. They parallel some chlorite veins, many quartz veins, and many normal faults north of the granite, and they strike normal to the regional structural grain, the northern granite margin, and to most cleavage and schistosity in the northern part of the area. They are also roughly parallel to the margins of the Okpilak batholith along its eastern and western exposed limits, as well as to several minor irregularities along its south and north margins. Linears that probably represent this joint set are conspicuous on aerial photographs of the eastern part of the batholith.
2. Joints that strike north (±20°) and dip steeply to vertically. These are closely parallel to many chlorite and quartz veins and to some shear zones in the granite; they are locally parallel to primary foliation features in subareas V and IX. Conspicuous linears shown on aerial photographs of the western part of the batholith probably reflect this joint set.
3. Joints that strike N. 30°–45° E. (to N. 60° E. in subareas VI and VII) and dip moderately to steeply south and north. Pole maximums showing moderate dips in subareas VI and IX represent mutally conjugate sets. The strike of these joints is subparallel to the elongation of the batholith and locally coincides with schistosity and feldspar-biotite foliation trends in the south-central and eastern parts. Linears that trend N. 45° E. are conspicuous on aerial photographs of the eastern part of the batholith.
4. Joints that strike roughly east (±15°), commonly east-southeast, and that are variable in dip attitude and direction. These are not as prominent as other joint sets in the area examined although they may be better developed in the western part of the batholith. Where steeply dipping, they seem to form a conjugate system with northward-trending joint sets (subareas VII and IX). The east-striking moderately north- and south-dipping joint sets in subarea V appear to be closely related to trends of quartz veins, and a similar relationship may be present in subarea IX. Vein attitudes, however, as indicated by their overall sporadic distribution, are not consistently controlled by the joint patterns shown on plate 2.

Joint sets 1 and 2 appear to be the dominant and perhaps latest sets in the area. They are even and persistent and cut all rocks, including those of Cretaceous age north of the area, and locally cut and displace joints of sets 3 and 4. Although they are discrete sets at many localities, their range in strike may overlap in such a manner that, for example, N. 15° W. joints in some subareas may genetically represent part of the N. 30°–45° W. set in others.

In subarea VIII, in and near the Jago stock, the equal-area projection shows a pattern somewhat similar to that in subarea IX. Joints in subarea VIII consist of (1) nearly vertical joint sets that strike E. and N. 60° E., (2) moderately to steeply dipping, possibly related sets that strike N. 30°–45° W., and (3) a set that strikes north and dips less than 30° E. The N. 60° E. set clearly corresponds with feldspar and biotite foliation in the central part of the stock, and linears examined on aerial photographs indicate that this set is prominent in at least the west half of the exposed body.

INTERPRETATION

Joint trends in the rocks north of the batholith and in the marginal granite adjoining them are generally similar. Although joint patterns within the pluton are more complex, the orientations of some elements are obviously related to the joints in the sedimentary rocks. Most features in the exposed levels of the pluton which can be ascribed to primary flow structures (Balk, 1937) are steeply dipping and do not reflect a simple domal pattern. In some localities where primary lineation and foliation are strongly developed, three prominent joint sets correspond well to the cross joints, longitudinal joints, and joints parallel to foliation discussed by Balk (1937, p. 27–40). In other exposures, however, joint sets are more closely related to secondary features. Interpretations for the origin of dominant joint sets include: (1) Most joint sets in the granitic rocks represent the primary fractures in plutons described by Balk; (2) joint sets were caused by later orogenic stresses. I believe that the fracture systems initiated during emplacement of the granite largely controlled later fracturing.

Steeply dipping joint sets 1 and 2 in the granitic rocks are broadly interpreted to be longitudinal and diagonal joints respectively. Set 1 in many areas is locally parallel to primary lineation and normal to foliation. These even, dominant fractures were reactivated as slip surfaces during a later orogeny and controlled directions of normal faults. Joint sets in rocks north of the pluton corresponding to sets 1 and 2 are considered to be extension and shear joints, respectively, and to be generally contemporaneous with the northward-trending normal faults.

Joints of set 3 may correspond to the inward-dipping joints of Balk (1937, p. 109), indicating that stresses were directed upward along a northeast-trending axis. They may also in part represent cross joints or later shear fractures reflecting horizontal couple or compression.

Joints in set 4 are difficult to relate to stress patterns which produced the other sets. They may represent diagonal joints (Balk, 1937, p. 37–39), or they may be shear joints resulting from later northward-directed stress.

Analysis of fracture patterns in relation to other structural features in the Romanzof Mountains is based upon the assumption that dominant joints were superimposed on the sedimentary rocks by a simple stress field in which compression or horizontal couple acted in a north-northwesterly direction. The joint sets do not appear to be everywhere related to primary granite features or feldspar foliation; in some areas they are parallel or normal to secondary biotite foliation, schistosity, and shear zones. Thus, the dominant joint pattern in the sedimentary rocks is probably younger than fractures related to the initial phase of granite consolidation. A simple hypothetical stress field can roughly accommodate many of these (fig. 23); it is based on the assumption that north-northwesterly joints represent extension jointing.

SUMMARY OF STRUCTURAL DATA

Primary structural and textural elements in the granitic rocks are strongly masked by late-stage or postconsolidation deformation effects. They suggest, however, that the pluton was emplaced as an elongate northeast-trending, somewhat mushroom-shaped body with perhaps several intrusive centers. Late-stage consolidation features such as dike-filled fractures are generally parallel or normal to elongation directions or boundaries of the pluton. Other late-stage or postconsolidation features such as biotite foliation, schistosity, mineral-filled fractures, transverse faults, and joints are interpreted to have developed during strong deformation characterized by north-south com-

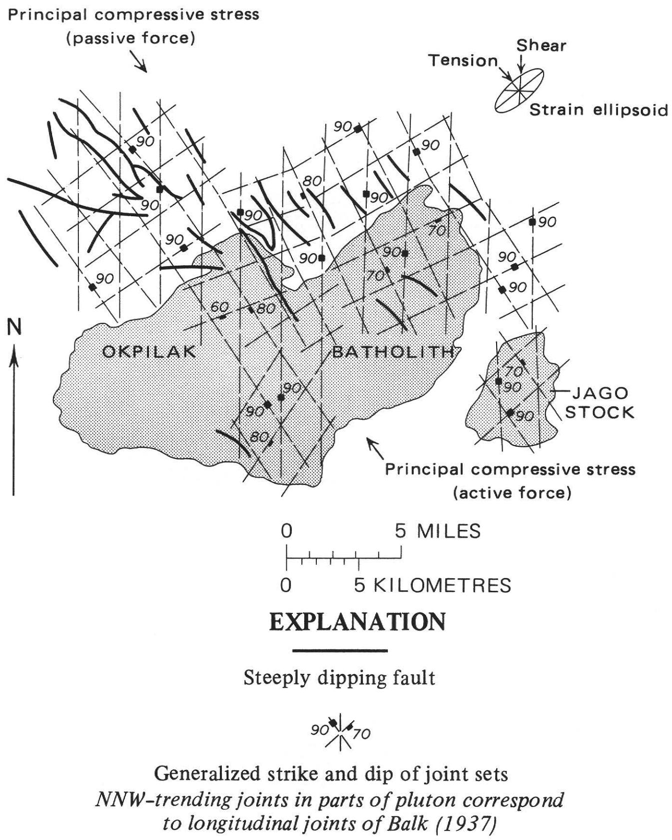


FIGURE 23.—Sketch map of Romanzof Mountains area showing selected prominent joint set and fault trends resulting from hypothetical stress field.

pression and resultant east-west extension which affected the entire area. This deformation may have closely followed granite emplacement, but my opinion is that it occurred much later. The strong correlation of biotite foliation and schistosity to pervasive cleavage in post-Neruokpuk rocks north of the batholith indicates that this deformation was post-Jurassic, but the age of biotite foliation and biotite alteration relative to the time of granite emplacement is not determinable from the evidence at hand.

MODE OF EMPLACEMENT

The granite mass is interpreted to be a synorogenic pluton resulting mostly from melt crystallization and emplaced as a mobile body by forceful injection with minor wall and roof(?) stoping. The granite body apparently has an elongate-funnel shape in cross section and is a composite pluton, as inferred from its primary foliation trends and the apparent textural facies distribution. A melt origin is inferred from the following features.

1. The rather uniform composition of the granitic rocks irrespective of the nature of truncated country rock.
2. Sharp and irregular contact relationships in an area of lowgrade metamorphic rocks, and large-scale truncation of country rock units.

3. Inclusions with sharp boundaries.
4. Normal zoning in plagioclase.
5. Granoblastic textures in areas of undeformed granite.
6. Included crystals showing sharp boundaries with their hosts.

Cataclastic (autoclastic?) textures may indicate that crystallization was far advanced at the time of intrusion, but parts of the mass, at least, were fluid enough to penetrate narrow fractures in the wallrock. The melt was probably relatively dry, as reflected by the scarcity of pegmatite and by the small areas of mineralization ascribed to volatile materials. Deformation continued into the deuteric stage. The high degree of physical deformation may reflect high viscosity, the result of low fluid content, but I believe it was the result of much later postconsolidation deformation. Possible reasons for origins of the textural facies have been given on page 40. Structureless granite, locally present in the coarse inner facies, appears to have crystallized following the orogenic maximum.

The low metamorphic grade of the country rocks, compound emplacement relationships, well-developed steep planar foliation, common aplites, and contact metamorphic aureoles are features which are ascribed to plutons emplaced in the mesozone (Buddington, 1959, p. 695–697). Features of this pluton and its environment generally fit these criteria.

AGE

Either Paleozoic or Mesozoic age possibilities, or both, for emplacement of the granitic pluton are suggested by latoratory age determinations, field evidence, and regional tectonic considerations. The evidence for the widely different ages presented in the following pages seems to be about evenly divided; conclusions are in large part dependent on interpretations of relative weight of this evidence. The possibility that the pluton was emplaced in mid-Paleozoic (Devonian) time and underwent a mid-Mesozoic (Cretaceous) metamorphic episode which reconstituted some of its mineral constituents has been favored by me (Sable, 1965, p. 174). This serves to unite several lines of evidence that are contradictory when relating the granite to a single tectonic event. I currently favor the possibility that the main mass of the granite pluton is Devonian in age, but that recrystallization and perhaps local remobilization of the granite occurred during Cretaceous time.

LABORATORY EVIDENCE

Age determinations of two samples of granite of the Romanzof Mountains by the U.S. Geological Survey include lead-alpha determinations on zircon and K-Ar determinations on biotite. Sample 57ASa160 was collected at about the contact between porphyritic and variable facies and composite sample 58ASa188-195 is from the porphyritic facies. They were collected at relatively low altitudes along the east and west sides of the Okpilak River valley (pl. 1).

The lead-alpha determinations are shown in table 10; considerable differences in calculated ages are evidenced. Age of sample 57ASa160 was calculated as 310±35 m.y. From sample 58ASa188-195, the calculated age difference between the two zircon fractions, 360 and 450 m.y., appears to be outside the expected experimental limits and may be an experimental error or it may be due to the presence of trace amounts of common lead in the magnetic fraction, according to T. W. Stern (written commun., 1960). Stern stated that "we would select the younger age as probably being closer to the true age."

K-Ar determinations on partly chloritized biotite in the two samples listed in table 11 indicate calculated ages of 128 and 125 m.y., considerably younger than those determined by the lead-alpha methods. The K-Ar determinations are shown in table 11.

The lead-alpha dates fall in the Late Ordovician to middle Carboniferous on the Holmes (1959) time scale and may suggest an Acadian or Caledonian age for granite em-

TABLE 10.—*Lead-alpha age determinations of zircon from Romanzof Mountains*

[Ages are rounded off to the nearest 5 m.y. α counts by T. W. Stern; lead determinations by Nola B. Sheffey]

No.	α/mg-hr	Pb (ppm) Individual determinations	Pb (ppm) Average	Calculated age (m.y.)
		Sample 57ASa160 [Lat 69°20.75′, long 144°00.5′]		
1	655	80, 88	84 k	310±35
		Composite sample 58ASa188-195 [Lat 69°20.9′, long 144°05.2′]		
2[1]	538	80, 74, 80, 88	80	360 } 405±45
3[2]	747	135, 145	140	450 }

[1]Nonmagnetic fraction.
[2]Magnetic fraction.
NOTE.—The lead-alpha ages were calculated from the following equations:

(1) $t=\frac{CPb}{\alpha}$

t=age in millions of years
C (a constant based on the assumed Th/U ratio of 1)=2485
Pb=lead content in parts per million
α =alpha counts per milligram per hour

(2) $T=t-\frac{1}{2}kt^2$

T=age in millions of years correct4d for decay of uranium and thorium
k=decay constant based upon Th/U ratio=1.56×10^{-4}

TABLE 11.—*Potassium-argon age determinations of biotite from Romanzof Mountains*

[Potassium determinations made with Perkin-Elmer flame photometer with lithium-internal standard. Overall analytical error approximately ±5 percent. Analysts: H. H. Thomas, R. F. Marvin, P. L. D. Elmore, H. Smith]

Lab. No.	K^{20} (percent)	K^{40} (ppm)	[1]Ar^{40} (ppm)	Radiogenic Ar^{40} (percent)	[1]Ar^{40}/K^{40}	Age (m.y.)
			Sample 57ASa160 [Lat 69°20.75′, long 144°00.5′]			
283 B	7.59	7.69	0.0596	89	0.00775	128
			Sample 58ASa188-195 [Lat. 69°20.9′, long 144°05.2′]			
284B	7.19	7.28	0.0548	79	0.00753	125

[1]Radiogenic argon.
NOTE.—K^{40} decay constants: $\lambda\varepsilon=0.585\times10^{-10}$/yr, $\lambda\beta=4.72\times10^{-10}$/yr
Abundance ratio: K^{40} 1.22×10^{-4}gm/gm K

placement. The K-Ar dates are Early Cretaceous. Two possible explanations for the wide discrepancies between the two types of age determinations are: (1) All deformation in the area is the result of one essentially synchronous Mesozoic granite emplacement, and the zircons represent constituents of older rocks, and (2) upper Paleozoic granite in which zircons were crystallization products has been affected by Mesozoic deformation and metamorphism.

Whether the zircons are products of melt crystallization or whether they largely represent grains that predated granite emplacement is a pertinent question, but results of examination of thin sections made in an attempt to recognize different color and shape varieties of zircon are inconclusive. Most of the zircon is associated with biotite, but color recognition is uncertain because of the completely metamict nature of smaller grains. Some discrete clear euhedral crystals of zircon are present in the groundmass, but many grains are cloudy and subround. No overgrowths on zircon grains were seen.

FIELD EVIDENCE

The granite clearly postdates rocks of the Neruokpuk Formation, but its relationships with the Kekiktuk Conglomerate which locally overlies the granite are uncertain. The base of the Kekiktuk overlies a regional unconformity. In many localities relationships between granite and Kekiktuk rocks are gradational through a schistose zone, and the Kekiktuk seems to be slightly altered. That the granite definitely alters or intrudes Kayak(?) or younger rocks is not certain. These relationships appear to narrow granite emplacement to pre-Kekiktuk time or post-Kekiktuk and pre-Kayak(?) time, and they indicate that the granite may be Late Devonian in age. Other evidence that supports this view follows:

1. No inclusions definitely known to be Kekiktuk, Kayak(?), or younger rocks were seen in the granite; most of the inclusions resemble quartzitic rocks in the Neruokpuk. Inclusions of carbonate rocks on the west margin of the Okpilak batholith may be from the Lisburne Group, but I believe they are Neruokpuk rocks.
2. No pegmatites, aplites, granite apophyses, or mineralization other than pyrite, quartz, and calcite were seen in known post-Neruokpuk rocks. However, quartz veins are common in all rocks, and one minute tourmaline crystal aggregate was seen in the Kekiktuk.
3. Bedding in Kekiktuk rocks that adjoin granite-schist transitional zones is at least locally discordant with primary granite features, such as feldspar foliation, seen along the east side of the Jago stock.
4. Much of the granite is highly deformed and gneissic, and the degree of deformation seems more in keeping with that in pre-Mississippian rocks. Although younger rocks are highly folded and faulted, they do not appear to have been subjected to two or more different stress directions as some of the older rocks have. The granite also exhibits diverse foliations and dislocations that are difficult to ascribe to one period and orientation of stress.
5. The map pattern (pl. 1) strongly indicates an unconformity of great magnitude at the base of the Kekiktuk-Kayak(?) map unit. Its age would roughly coincide with the younger Paleozoic lead-alpha dates in the granite of the Romanzof Mountains.
6. Low-grade retrograde metamorphism of postgranite mafic dikes seems to correspond to the alteration of biotite and tourmaline to chlorite in the granite rocks.
7. Tourmaline-quartz pebbles and a heavy mineral suite that contains abundant tourmaline, as well as cassiterite, sphene, ilmenite, and zircon, are found in the Kekiktuk Conglomerate of the Lake Peters area (Reed, 1968, p. 30–33, 96). Optical properties of the tourmaline given by Reed are similar to those in granitic rocks of the western Romanzof Mountains which Reed suggests were a source area for tourmaline-bearing Kekiktuk rocks.
8. Gradational schistose rocks occur between Kekiktuk quartzites and granite. Gradations from enclosing schistose rocks into granite are abundantly reported in the literature (for example, Grout, 1933; Turner and Verhoogen, 1960, p. 359), and the schistose textures and mineralogy are generally interpreted to be contemporaneous with emplacement of the granitic rocks. Other speculations are possible for the Kekiktuk-granite transitional zone of this area and could be used to support a Paleozoic age for the granite of the Romanzof Mountains, upon which effects of a later orogeny are superimposed. Possible explanations for a postgranite age of the apparently transitional rocks depend on the assumption that their schistosity, the cleavage in overlying rocks, and the biotite foliation in the underlying granite all developed after the overlying sedimentary rocks were deposited or faulted into their present position relative to the granite. The transitional schistose rocks might represent (1) a metamorphosed pre-Kekiktuk regolith rich in iron oxides, quartz grains, and remnants of partially weathered microcline megacrysts and altered biotite; (2) metamorphosed zones along bedding-plane shear zones; or (3) products of metasomatism by local diffusion of material from the granite into quartz sandstones and pelitic rocks during a later orogeny. All of these are speculative. Seemingly an encroaching sea would strip a soil layer of probably less than 50 feet before depositing its own reworked sediments. It also is unlikely that, in a structurally anistropic sequence, the Kekiktuk should form the base of allochthonous

blocks in widely separated areas. Finally, the intensity for recrystallization of Kekiktuk sedimentary rocks to schist seemingly requires conditions in which much of the overlying rock column would be metamorphosed to a higher degree than it is.

If, however, the granite postdates the Kekiktuk Conglomerate and the Kayak(?) Shale, then the age of emplacement is probably Mesozoic. This would imply that most of the complex structural features described in this paper are related to an orogenic cycle accompanying granite emplacement. Field evidence that may support an Early Cretaceous age for granite emplacement follows:

1. The possibility that limestone beds that are intruded and altered along the western margins of the granite are Lisburne Group rather than part of the Neruokpuk Formation as previously believed (Sable, 1965). These rocks, interbedded with black limy shales along Esetuk Glacier and south of Kolotuk Creek, are similar to strata in the sandy limestone unit of the Alapah Limestone, contain scarce crinoid columnals, and locally overlie dark phyllites which might be Kayak(?) Shale. Possible structural complexity, however, complicates interpretation of the stratigraphic position of these rocks because a broad belt of Kayak(?) and Kekiktuk strata south of Kolotuk Creek also structurally overlies the limestones. I believe that the limestones are pre-Kekiktuk strata, perhaps equivalent to lower units of the Katakturuk Dolomite (Dutro, 1970, p. M2) or to carbonate units in the Neruokpuk (Dutro and others, 1972), dipping away from the granite body and normally underlying the broad belt of Kekiktuk and Kayak(?) rocks.
2. The coarsening of metamorphic grain size in the rocks tentatively correlated with the Kayak(?) Shale toward the granite on the west side of the batholith. Although these dark phyllites and slates are not in themselves distinctive, and could therefore be part of the Neruokpuk Formation, they contain thin orange-weathering limestone beds with poorly preserved horn corals and brachiopods which, in this part of the area at least, have been recognized only in the Kayak(?). Near the granite, these rocks are schistose and some exposures contain dark hornfelslike rocks.
3. The parallelism of dominantly south-dipping cleavage in Mississippian through Jurassic rocks and biotite foliation in the northern part of the pluton. This possibility is based upon the assumption that the biotite foliation is a late-stage primary feature. (See "Correlation of Structural Elements.")
4. The apparent lack of granitic detritus in clastic rocks of Mississippian through Jurassic age. Feldspars similar to those found in the granite of the Romanzof Mountains are present, however, in sandstones ascribed to the Ignek(?) Formation (Cretaceous), as well as in pregranite Neruokpuk Formation. Granitic detritus is also lacking in Paleozoic detrital rocks of the south-central Brooks Range, although Cretaceous conglomerates contain such detritus (W. P. Brosgé, written commun., 1962).
5. Fairly widespread silicification, quartz veins, and locally abundant disseminated pyrite in all pre-Cretaceous rocks.
6. The presence of inclusion-rich chlorite and sericite patches in Kekiktuk schistose rocks near granite contacts which closely resemble altered biotite in the granite.
7. The presence of tuffs of unreported composition in the upper part of the Cretaceous Ignek Formation northwest of the Romanzof Mountains (Keller and others, 1961, p. 206).

INTERPRETATION

Evidence for either Paleozoic or Mesozoic granite emplacement is inconclusive. Some evidence seems to be flatly contradictory, such as the presence of detrital tourmaline in the Kekiktuk of adjoining areas as against apparent intrusion effects in the Kekiktuk in this area. Some evidence requires further investigation, such as the possible Mississippian age of the sandy limestones which the granite intrudes and alters on the west side of the batholith. Observations that seem most suggestive of a Paleozoic age for the granite are the presence of detrital tourmaline in the Kekiktuk of nearby areas and the fact that the granitic rocks are nowhere known with certainty to intrude units younger than the Kekiktuk, which overlies the granite at many localities and the base of which is unconformable on several older units. Conversely, indications of Mesozoic age for the granite are the parallelism of biotite foliation in granitic rocks to cleavage in the Mississippian-Jurassic sequence, provided that the biotite foliation is an emplacement feature, and the aforementioned possibility that intruded limestones are of Mississippian age. The disparate zircon ages may reflect mixing of more than one generation of zircons during assimilation or melting of country rock.

Several granitic plutons in northwestern Canada and northeastern Alaska have been dated by radiogenic methods (table 12). Bimodal age results are characteristic when zircon Pb-alpha and biotite K-Ar ages are compared, as in rocks from the Okpilak batholith and plutons on the Chandalar and Alatna Rivers, southern Brooks Range, Alaska. The zircon ages are consistently older, and, although they show wider age ranges than the K-Ar ages even within the same pluton, some of them, such as the Okpilak batholith (310–405 m.y.) and the Chandalar pluton (380 m.y.), suggest Paleozoic ages that are reasonably similar. Farther east, within the Yukon Territory and along the Canadian border, K-Ar isotopic ages of Mount Fitton (353 m.y.) and Mount Sedgwick (355 m.y.) granites,

TABLE 12.—*Radiogenic age determinations of granitic rocks in northeastern Alaska and extreme northwestern Canada*
[ND, not determined]

Name of pluton or batholith (fig. 23)	References cited	Pb-α age in m.y. (determination on zircon)	K-Ar age determinations (m.y.)	K-Ar age determinations Mineral
Okpilak batholith	Sable (1965)	310±35	128	Biotite, partly chloritized.
		[1]405±45	125	Do.
Old Crow batholith	Baadsgaard, Folinsbee, and Lipson (1961)	ND	220	Biotite, chloritized.
	Wanless, Stevens, Lachance, and Rimsaite (1965).	ND	265±12	Do.[2]
	Bassett and Stout (1967)	ND	345±10	Biotite(?)
Chandalar pluton	Brosgé and Reiser (1964)	380±40	103	Biotite.
			100	Muscovite.
			125	Biotite.
Hodzana pluton	do	140±20	101	Do.
Alatna pluton	do	280±30	86	Do.
			88	Do.
		240±30	92	Muscovite.
Mount Sedgwick pluton	Baadsgaard, Folinsbee, and Lipson (1961)	ND	95	Biotite, chloritized.
	Wanless, Stevens, Lachance, and Rimsaite (1965).	ND	355	Hornblende.
Mount Fitton pluton	do	ND	353	Biotite.
		ND	370±16	Biotite.[3]
Okpilak "offshoot(?)", Jago River.	Reiser (1970)	ND	431±13	Hornblende.

[1]Average of two determinations, 360 and 450 m.y.
[2]Chlorite content 30 percent.
[3]Chlorite content 20 percent.

on biotite and hornblende respectively, correspond to each other and to the Okpilak and Chandalar zircon ages. Ages such as these have been interpreted as evidence for Caledonian or Acadian orogeny in the northern Yukon Territory (Baadsgaard and others, 1961). K-Ar ages of most northeastern Alaskan granites are considerably younger; they, too, fall within a limited age range and suggest Cretaceous events, except for the hornblende granite south of the Okpilak batholith which gives 431 m.y. (Silurian) age (Reiser, 1970, p. K4). Assuming that both K-Ar and Pb-alpha dates are reasonably correct, a pattern of two main orogenic episodes (middle Paleozoic and Cretaceous) emerges. Some ages, such as the K-Ar determinations for the Old Crow batholith (220–265 m.y.) and Pb-alpha ones for the Alatna pluton (240–280 m.y.), may indicate an intermediate event.

As a group, then, the preceding isotopic dates seem to relate to two main tectonic episodes and tend to support the hypothesis of both Paleozoic and Mesozoic granite emplacement in northwestern Canada and northeastern Alaska. Late Devonian paleogeographic reconstruction also suggests Paleozoic unrest in this region. (See "Tectonics.")

For the Okpilak batholith, it is difficult to envisage a Mesozoic metamorphic episode that affected a Paleozoic granite to the extent of updating the biotite by recrystallization resulting from progressive metamorphism without evidence of higher grade metamorphism in at least some of the upper Paleozoic and Mesozoic rocks. The possibility of retrograde metamorphism, during which chloritization of biotite occurred with resultant loss of argon, however, may account for the younger ages determined from the biotite samples. Such a possibility has been considered for chloritized biotite from the Mount Sedgwick granite, Yukon Territory (original report by Baadsgaard and others, 1961, discussed by Wanless and others, 1965, p. 23).

In summary: (1) The granitic rocks are largely of magmatic, syntectonic emplacement origin, as indicated by country-rock relationships, general composition, and structural features. Assimilation of quartzose country rock of large enough scale to affect composition of the granite is suggested. Potash metasomatism is indicated by microcline megacrysts in invaded country rock and marginal areas of granitic rocks.

(2) I believe that the granitic rocks were initially emplaced during a Silurian or Devonian orogeny which affected northeastern Alaska and northwesternmost Canada. Supporting evidence consists of the major unconformity between Upper Devonian or Mississippian strata and older rocks, regional Late Devonian paleogeographic reconstruction, and other granitic bodies in this region of Canada and Alaska which are dated as Devonian or Silurian in age. If emplaced during the Paleozoic (Devonian?), the granitic rocks were overprinted by Cretaceous orogeny with attendant severe deformation and reheating, with possible local remelting. Retrograde metamorphism, expressed largely by chloritization of biotite in granitic and pre-Mississippian rocks and progressive low-grade metamorphism in younger rocks, then followed.

MAFIC HYPABYSSAL AND VOLCANIC ROCKS

DISTRIBUTION, CHARACTER, AND COMPOSITION

Dikes of grayish-green metamorphosed basalt (greenstone) occur in several areas in the Okpilak batholith and in Neruokpuk Formation (pl. 1). Mafic volcanics consisting of similar rock types, in part amygdaloidal, associated with purple and gray slaty and phyllitic rocks are exposed along the Hulahula River, Old Man Creek, and adjoining the terminus of Esetuk Glacier. A somewhat similar-appearing sequence adjoins the granite pluton from Esetuk Glacier south across Kolotuk Creek; it is questionably assigned to these rocks (pl. 1). A small area of amygdaloidal greenstone is also exposed along the Okpilak River, north of the granite.

The mafic dikes, a few feet to about 400 feet thick, are best developed in the northeastern part of the Okpilak batholith where they trend N. 30° E. and dip steeply northwest. At most places dike walls are sheared, so that contact relationships are not everywhere clear. Locally however, the dikes contain inclusions of granitic country rock and chilled border phases. In the exposures examined, primary features within these dikes have been masked by schistosity and mineralogical alteration. Minerals consist of sericitized plagioclase microlites, epidote, sericite, and chlorite, with felted texture. Some are entirely chlorite-sericite rock with highly fractured garnet metacrysts.

Mafic volcanics covering about 6 square miles along the Hulahula River have been reported by Leffingwell (1919, p. 26) and C. L. Whittington and E. G. Sable (1948, p. 16; unpub. data, 1960). Mineralogically these rocks are like the mafic dikes in granite; chlorite and calcite are the chief amygdule fillings, and chlorite-filled amygdules also occur in the exposure along the Okpilak River. Leffingwell reported augite, plagioclase, and a little quartz in these greenstones. Purple, green, and gray aphanitic rocks with slaty cleavage along the Hulahula River are probably metasedimentary rocks interbedded with the basalts.

The metamorphosed basalts along the Hulahula River have been interpreted to be of volcanic origin (C. L. Whittington and E. G. Sable, unpub. data, 1960; Reiser, 1970). Rocks of generally similar composition occur in other northeastern Alaskan areas, such as the Sadlerochit Mountains (Whittington and Sable, 1948) and east of the Romanzof Mountains (Mangus, 1953, p. 18–19). Some of the rocks are medium-grained varieties and occur in sill-like bodies. A thin section of one of these rocks from the Sadlerochit Mountains, northwest of the Romanzof Mountains, was examined by me. The rock is a relatively unaltered gabbro with diabasic to ophitic texture and contains plagioclase, about An_7 (52 percent); augite (31 percent); graphic intergrowths of quartz and feldspar (7 percent); magnetite (6 percent); and quartz (4 percent). A similar mineralogy is recorded for an altered basalt about 70 miles east of the Romanzof Mountains area, except that the pyroxenes are completely altered to chlorite or magnetite or are replaced by carbonates (Wanless and others, 1967, p. 49).

AGE

In the Romanzof Mountains, the mafic dikes are clearly younger than many units of the Neruokpuk Formation; they also postdate the granite, but their upper age limit is not known. The outcrop pattern (C. L. Whittington and E. G. Sable, unpub. data, 1960) along the Hulahula River indicates that the Kekiktuk-Kayak(?) unit of this report unconformably overlies both the mafic volcanics and the Katakturuk Dolomite. If the granitic rocks are Devonian(?) in age, the mafic dikes are also provisionally considered to be Devonian. Whole-rock age determinations from the altered basalt east of the Romanzof Mountains area are reported by Wanless, Stevens, Lachance, and Edmonds (1967, p. 49). They suggested that the 237±47 m.y. (unleached sample) and 253±45 m.y. (leached sample) ages may relate to the time of rock alteration, in effect dating the body as contemporaneous with or older than these ages.

STRUCTURE

The Romanzof Mountains comprise a structurally positive area and contain structural elements resulting from both vertical uplift and northward horizontal movement. The dominant structural grain strikes east-northeast, and many structural elements dip south.

The Okpilak batholith is the major positive structural element within the area; it lies along a complex anticlinorial belt which can be traced at least 60 miles east to the Alaska-Yukon boundary. In general, rock units dip away from the batholith. South of the pluton, dips are dominantly south for many miles beyond the mapped area. North of the pluton, a regional northerly dip prevails, which is interrupted by large anticlinoria west of the Hulahula River and probably by anticlinal structures of lesser magnitude in the coastal plain between the Hulahula and Jago Rivers.

Within the mapped area north of the Okpilak batholith, folds include east-northeast-trending anticlinal and synclinal structures from 1 to more than 6 miles in width with amplitudes of as much as 2,000 feet. These contain numerous smaller scale structures including folds which range from a few feet to several hundred feet in width and amplitude. Most of the small folds are asymmetric to overturned with south-dipping axial planes, many of which coincide with cleavage directions. A transverse fault system cuts all fold structures.

The degree of deformation increases southward toward the granite, and rocks in a belt one-half to 2 miles wide adjoining the northern exposed limit of the granite are characterized by recumbent folds and low-angle imbricate faults. Recumbent folds are best exposed along the north front of the granite between Okpirourak and McCall Creeks, and repetition of beds resulting from faulting and recumbent folding can be seen about 3 miles west of the Okpilak River. In these areas the granite is separated from Mississippian rocks by a zone of iron oxide-stained, sericitic to chloritic schistose granite and country rock of uncertain correlation as much as 1,000 feet wide. Although this seems to represent a zone of shear accompanied by retrograde(?) metamorphism, structural analysis suggests that the displacement, if any, may be only a few hundred feet.

Rocks adjoining the western and eastern sides of the Okpilak batholith, although complex in detail, dip away from the granite. In these areas, contact metamorphic effects and crosscutting granite country-rock relationships are well expressed.

Only small areas on the south side of the granitic pluton were examined in the field. In general, quartzites and slates of the Neruokpuk Formation strike concordantly around the granite in an arcuate pattern and dip away from the pluton at moderate angles (fig. 13). The section is probably repeated by south-dipping faults or isoclinal folding. Locally, beds of country rock adjoining the granite are vertical or contorted, and the granite is highly fractured and sheared. Along the west fork of the Okpilak River, the distinctive marginal porphyritic facies of the granite is absent, and there the Neruokpuk-granite contact may lie along a postgranite-emplacement thrust fault.

Major structures east of the Jago River, northeast of the Jago stock, trend east-northeast and are, from south to north, an east-plunging synclinorium in which Lisburne Group and Sadlerochit Formation rocks are exposed and a large complex anticlinorium along the trend of the Okpilak batholith, the north limb of which dips under the glacial deposits of the foothills. Structural details in this area are not well known; most beds dip south, and the section may be repeated by south-dipping reverse and thrust faults.

As a whole, the sedimentary rock mass in the Romanzof Mountains is structurally anisotropic, containing alternating competent and incompetent units. The incompetent units, such as the shale unit of the Ivishak Member of the Sadlerochit Formation, have yielded mainly by development of slaty cleavage, tight folding, and flowage. Internal flowage also characterizes some carbonate rocks of the Katakturuk Dolomite, but subsequent silicification and recrystallization have resulted in highly competent rocks. The carbonate rocks of the Lisburne Group are also

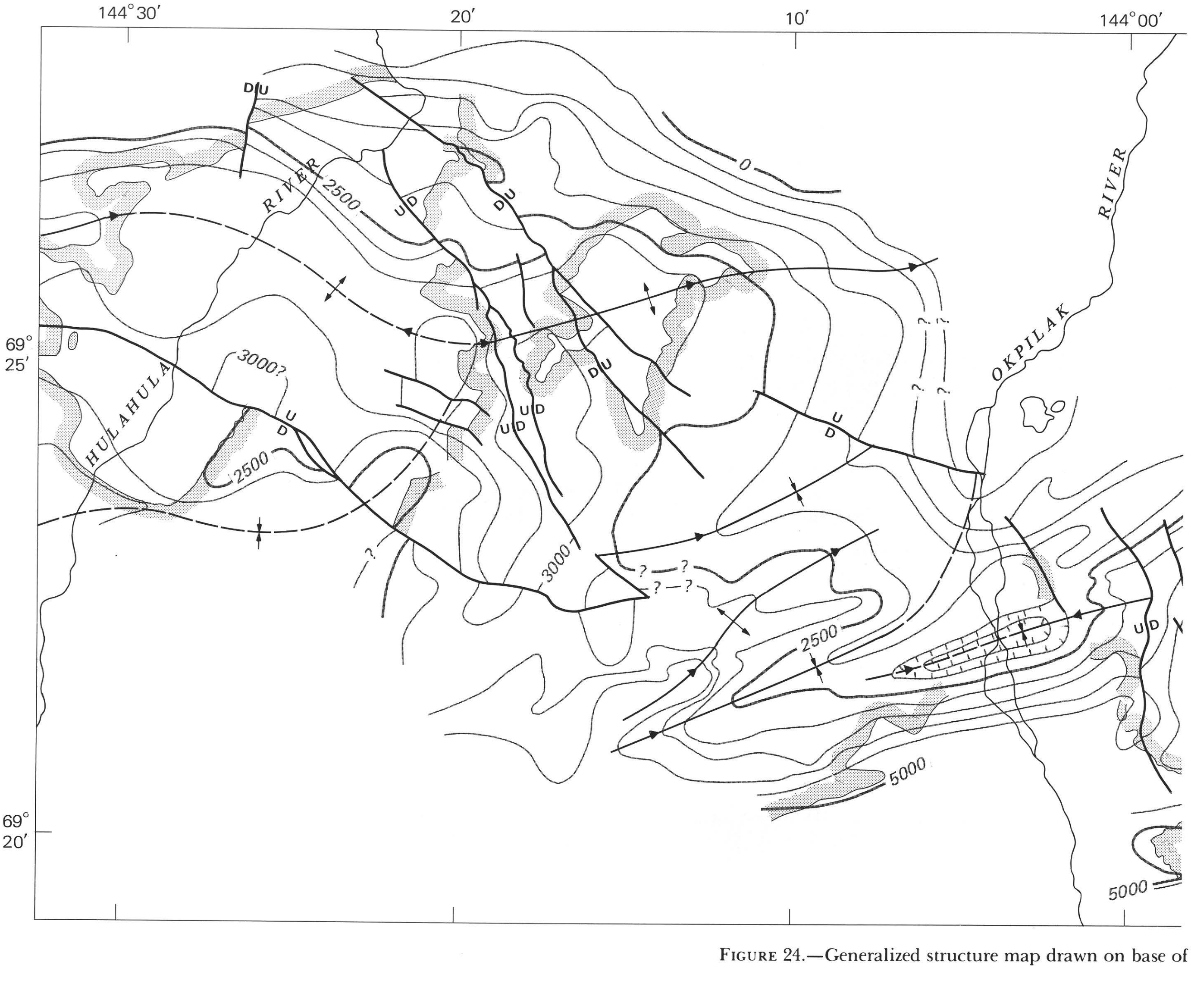


FIGURE 24.—Generalized structure map drawn on base of

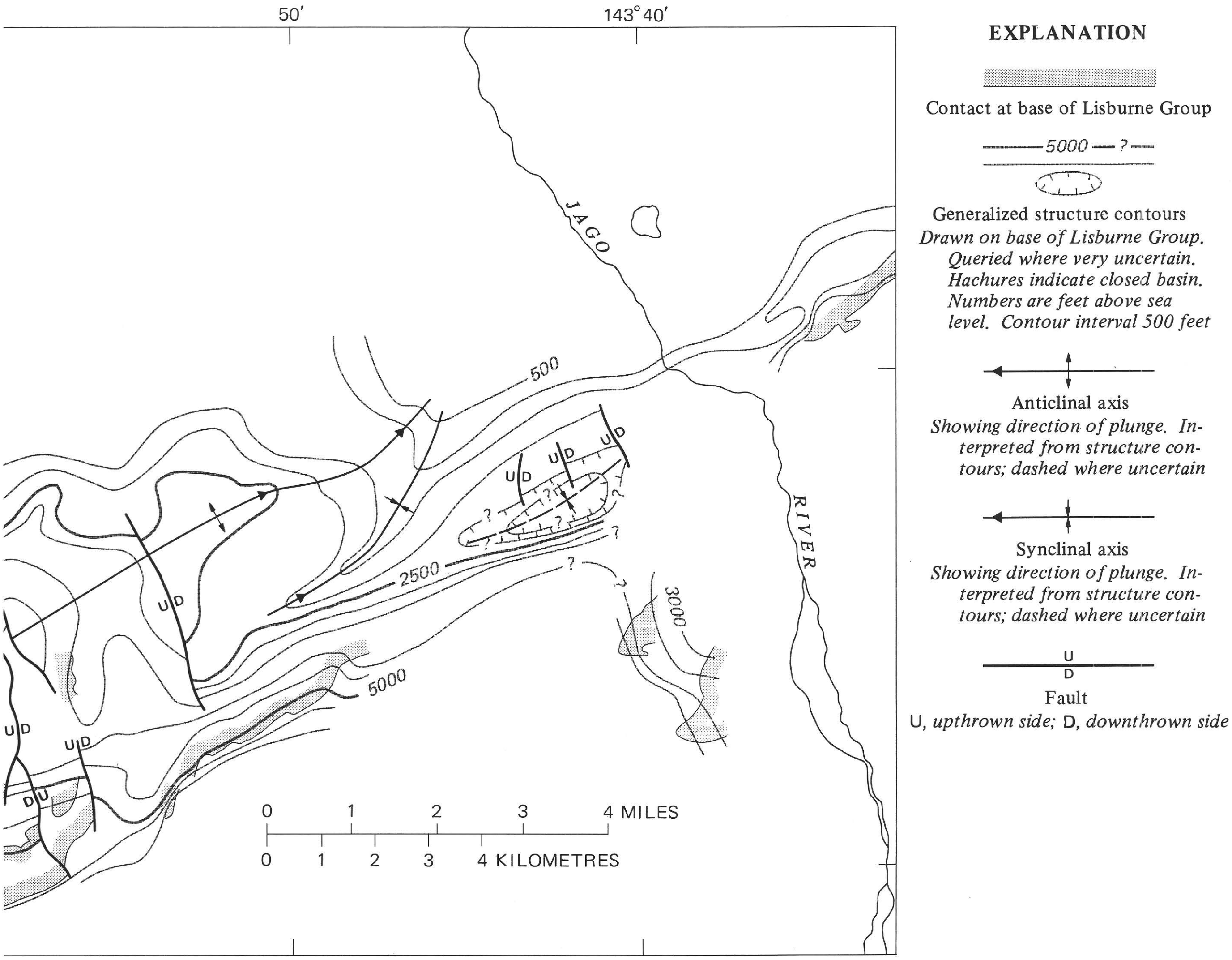
competent and have failed mostly by rupture, although tight folding is evident in some localities. The granite rocks are highly competent and have yielded by faulting, granulation, and the formation of schistose and gneissic structures.

The following discussion deals mainly with structural features in rocks exclusive of the previously discussed granitic rocks. Folds, cleavage, schistosity, and faults that have affected the sedimentary and metasedimentary rocks are described and analyzed; joints in these rocks have been analyzed previously along with those in the granite. Structural cross sections are shown on plate 1. In these, the coincidence of present topography with broad folds in the northern part of the area is striking. Although this feature may simply reflect resistant bedrock units that now control local levels of erosion, it probably is an expression of relatively recent broad folding, perhaps Tertiary or younger in age.

FOLDS NORTH OF OKPILAK BATHOLITH

Post-Neruokpuk Formation rocks north of the Okpilak batholith include several structural elements which appear to be related. These are subordinate to the major positive nature of the whole area (first order) and include several relatively large folds (second order) on which are superimposed numerous folds of smaller amplitude (third order). Cleavage and schistosity, steeply dipping transverse faults and joints, and normal and reverse parallel faults are also considered to be related features. The general strike of fold axes and cleavage is parallel to the north front of the Okpilak batholith and to the strike of secondary biotite foliation and schistosity within parts of the batholith. The orientation of joints, cleavage, and schistosity is shown on plate 2.

The relatively broad second-order folds shown on the generalized structure map, figure 24, strike east-northeast, appear to be asymmetric with axial planes dipping south,



Lisburne Group, north side of Romanzof Mountains, Alaska.

and most of them plunge east. Local west plunges occur east of the Hulahula and Okpilak Rivers, possibly indicating faults or shear zones along the river valleys. Along the northern front of the granite, closely spaced structure contours reflect a steepening of dip combined with small-scale imbricate thrusting and overturning of adjoining sedimentary rocks. Belts of schistose rocks along this margin suggest the possibility of reverse or thrust-faults of small displacement between the granite and sedimentary rocks to the north.

Strikes and plunge directions of third-order folds (pl. 1) generally correspond to those of the second order, although dips of axial planes of the third-order folds are more variable. These folds are best developed in the Ivishak Member of the Sadlerochit Formation, even where the underlying beds show little evidence of deformation (fig. 25).

CLEAVAGE AND SCHISTOSITY NORTH OF OKPILAK BATHOLITH

Slaty cleavage is well developed in rocks of Mississippian through Jurassic ages north of the granite (pl. 2). The cleavage strikes N. 60°–80° E., dips predominantly south, is consistent with general fold trends as well as secondary foliation in the northern part of the pluton, and closely parallels third-order fold axes. The parallelism of cleavage strike is less well defined in the vicinity of second-order fold axes, possibly indicating growth of these folds after cleavage had developed.

The cleavage is interpreted to be flow cleavage essentially contemporaneous with the third-order folds. Cleavage is also considered to be related to biotite foliation and schistosity in the adjoining granitic rocks (fig. 17, pl. 2), as well as to schistosity in the narrow belts of schistose rocks along the north margin of the batholith. All the preceding features are interpreted to have resulted from north-northwest compressive stress during a Mesozoic (Early Cretaceous?) orogeny.

FAULTS

Faults having apparent displacements from a few feet to more than 1,000 feet are best delineated in post-Neruokpuk Formation rocks north of the Okpilak batholith. Undoubtedly, numerous faults cut the granitic rocks, and many are probably of greater displacement than those to the north. Faults recognized in the area shown on plate 1 are as follows:

1. North- and northwest-trending high-angle transverse faults. This subparallel fault system is well developed north of the granite pluton between the Jago and Hulahula Rivers. The faults are mostly vertical to steeply west dipping, normal, and with apparent

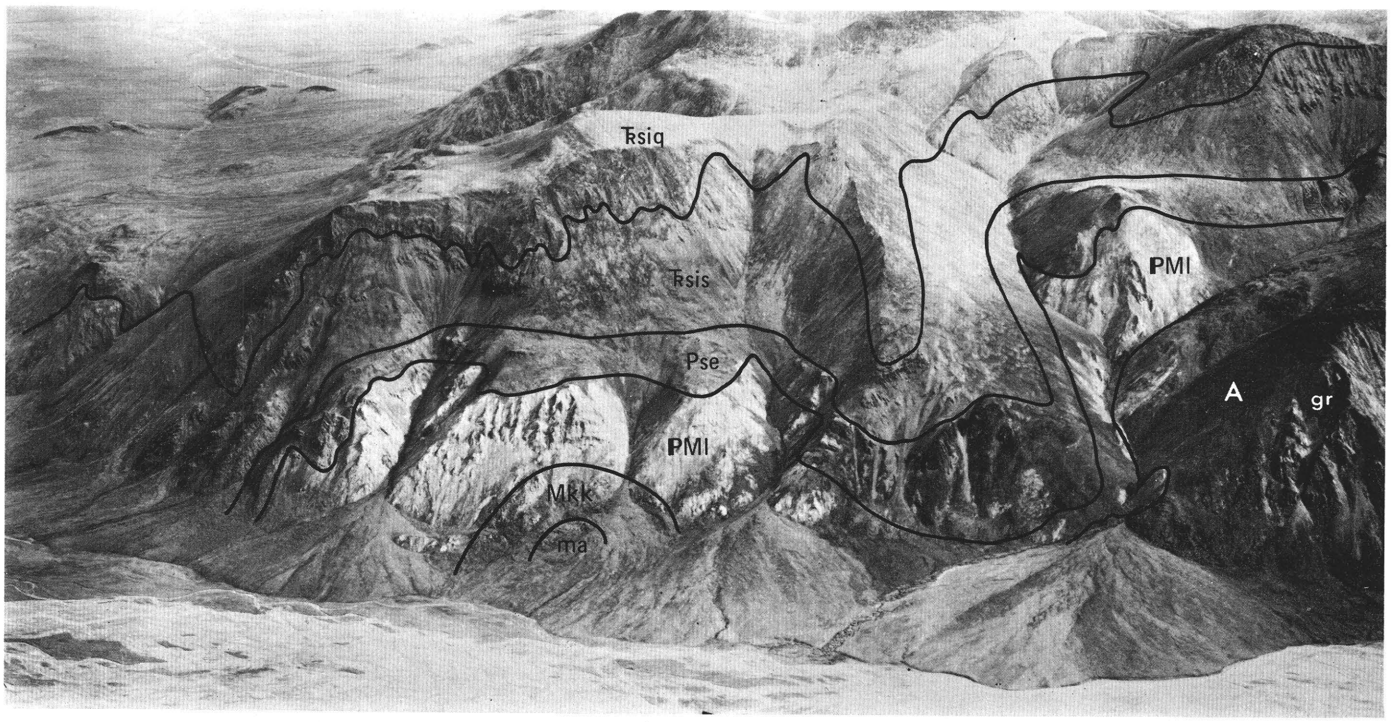


FIGURE 25.—Oblique photograph of east wall of Okpilak River valley at mountain front. Broad second-order anticlinal fold contains tight third-order folds visible along mountain front. South-dipping cleavage visible in left foreground. Faults not shown. Unglaciated terrace-like erosional benches at top of mountain. gr, granite; A, granite, Neruokpuk Formation, and younger rocks undivided; ma, mafic rocks; Mkk, Kayak(?) Shale and Kekiktuk Conglomerate; PMl, Lisburne Group; Pse, Echooka Member of Sadlerochit Formation; TRsis, shale unit, and TRsiq, quartzite unit, of Ivishak Member of Sadlerochit Formation. Ridges north of mountains composed of Jurassic Kingak Shale. Photograph by U.S. Navy.

stratigraphic displacements of from tens of feet to 1,200 feet. Marked silicification and brecciation occurs along some of the larger faults, and quartz-filled fractures associated with fault trends are common. Striated slickensides, where seen, are mostly steeply plunging, although some horizontal or shallow-plunging striae attest to strike-slip movement. Of 19 recorded striations, 18 are on steeply west- or south- dipping fault planes; 12 of the 18 ranged from 65° to 90°, and seven ranged from 0° to 26°.

2. Longitudinal high- to low-angle faults. These include both south- and north dipping reverse faults, as well as normal faults and imbricate fault structures. Maximum apparent displacement along these faults appears to be less than that of the transverse faults. South-dipping imbricate thrust faults of small displacement in sedimentary rocks along the granite front between the Jago and Hulahula Rivers have resulted mostly in repetition of the Lisburne Group sequence and appear to be the result of overriding of fold limbs in a late stage of isoclinal folding.
3. Low- to moderate-angle thrust faults of apparent large scale. East of the Jago stock, Neruokpuk quartzites, slates and granite have overridden Lisburne rocks. The exposed margin of the block dips southeast from nearly flat-lying to about 45°. Other thrust faults occur south of the Jago stock and the Okpilak batholith, and the southern limit of the Okpilak batholith may in part coincide with a thrust fault, as suggested by zones of intense deformation and known thrust faults along the east fork of the Okpilak River (fig. 26). Sugary-textured silicified zones in the granite are also related to probable shallow- to moderately-dipping thrust faults west of McCall Glacier.
4. Shear zones in the granitic pluton (see "Schistosity and Schistose Zones") are well expressed along the east wall of the Okpilak valley, 3-4 miles south of Okpilak Lake.

In addition to the faults just described, north-trending zones of faulting or sharp flexures may lie along the major river valleys. Structures in rocks on the west and east walls of the Jago River valley between the Jago stock and the mountain front indicate an apparent offset of Neruokpuk units along the valley, but neither the Jago stock itself nor post-Neruokpuk units along the mountain front appear to have been displaced. Such a relationship suggests that the dislocation may have predated granite emplacement. Along the east valley wall of the Okpilak River, numerous north-trending shear zones, faults, and linear iron-stained zones strike parallel to the valley, although no major displacement is obvious in the outcrop patterns on either side of the river. Along the Hulahula River valley, west of the mapped area, Triassic rocks are

FIGURE 26.—Oblique photograph of east fork of Okpilak River, looking southeast. Neruokpuk Formation (pMp€n)—units of quartzites and of phyllites and quartzites—in thrust-fault relationship with underlying Lisburne Group (PMl), Kayak(?) Shale and Kekiktuk Conglomerate (Mkk), and granite (gr). T's are on upper plate of thrust fault. Photograph by U.S. Navy.

exposed on the west side of the river (C. L. Whittington and E. G. Sable, unpub. data, 1960) but rocks of pre-Mississippian age constitute the east valley wall; a major dislocation with the east side raised up is probable here. The fault zones inferred along river valleys may reflect deep-seated zones of weakness in basement rocks and may therefore be reflections of forceful granitic intrusion in their interarea, or they may be zones of shear caused by movement of the structurally competent granite during a later orogenic maximum.

Longitudinal and thrust faults are ascribed to northward tangential movement, probably Cretaceous in age. The Okpilak batholith itself was probably moved upward and northward during this time, resulting in zones of shear along its north front and the overturning and imbricate faulting in the adjoining sedimentary rocks. Supporting evidence for postgranite thrusting is indicated by the sliver of granite in the thrust plate east of Jago stock (pl. 1). The northward-trending transverse faults are probably related to relaxation of compressional stresses and to uplift following the orogenic maximum. The fact that many of these have greater displacements in structurally positive areas may suggest that their initial development preceded uplift or that some late folding accompanied uplift.

Although the front of the Romanzof Mountains rises abruptly above lowlands to the north, there is no evidence for major faulting there. The topographic relief along the front is the result of differential uplift and resistance to erosion of the rocks exposed there.

TECTONICS

Although the dominant structural features in northern Alaska and adjoining Canada are the result of Mesozoic and early Tertiary deformation, several lines of evidence imply that late Paleozoic crustal unrest has affected parts of northwestern Canada and northern Alaska. Tectonic interpretations of northern Canada and Alaska have been summarized by Eardley (1962, p. 605–649); those of northwestern Canada include several regional syntheses (Martin, 1959; Bassett and Stout, 1967; Norris, 1967), and those of northern Alaska are from areal and regional reports (Brosgé and others, 1962; Gryc and others, 1967) and recent syntheses (Tailleur and Brosgé, 1970; Tailleur, 1969a, b). The following discussion suggests the possibility that a late Paleozoic orogenic belt accompanied by granitic intrusion has affected northern Alaska but has been largely masked by Mesozoic events (fig. 27).

Major Mesozoic and Cenozoic elements in northern Alaska (Payne, 1955) are the Brooks Range geanticline, a linear east-trending feature more than 600 miles long, flanked on the northeast by Romanzof uplift and, farther west, by the Colville geosyncline. South of this geanticline a major northeast-trending element is the Ruby geanticline, which intersects(?) the Brooks Range north of the Porcupine River.

The Brooks Range geanticline of Jurassic, Cretaceous, and Paleocene age is characterized by an east-trending structural grain with dominant south dips resulting from overturned folding and imbricate overthrust faulting. In contrast, the Romanzof uplift of Tertiary age, which includes the area of this report, is characterized by the development of large, complex, mostly west-plunging anticlinoria and synclinoria. Structurally, the Romanzof uplift is similar to the Brooks Range geanticline, but shows less intense deformation. Structures in the Brooks Range geanticline are comparable to those of the Rocky Mountains of western Alberta, and the Romanzof uplift contains structures more like those of the Rocky Mountains of Wyoming.

In the Yukon Territory, positive elements of Late Cretaceous or early Tertiary age (Martin, 1959, p. 2451) strike mostly southeast and south toward the Rocky Mountains of British Columbia and western Alberta and include several mountain groups. These belts contain elements similar to those in the Romanzof uplift and fault structures similar to those in the Alberta Rocky Mountains. The Romanzof uplift and adjacent areas in the Yukon Territory represent the maximum northward bulge of Rocky Mountain-type structures in northwestern North America. There is no good evidence for connections between structures in this bulge and Tertiary deformational belts in the Canadian Archipelago to the northeast. According to Martin (1961, p. 451), a nearly continuous depositional basin striking from the Romanzof uplift to Ellesmere Island was present during the Mesozoic. Martin (1959, p. 2442) also has postulated a Paleozoic eugeosyncline north of the Yukon Territory, now under the Arctic Ocean.

The emplacement of granitic plutons in northern Alaska and northwestern Canada is considered here to have corresponded with orogenic episodes. The Brooks Range is made up dominantly of sedimentary and metasedimentary rocks; a few granitic plutons are exposed west of long 150°, and several occur farther east. The northernmost of these is the Okpilak batholith, in the Romanzof uplift; the remainder lie in the Brooks Range geanticline province. Southwestward in Alaska, the Ruby geanticline contains many large granitic plutons (Dutro and Payne, 1957), most or all of which are considered to be Mesozoic, although many have not been dated by radiogenic methods. In the Yukon, granites in the Barn and British Mountains and Old Crow Range may be cogenetic with those in northeastern Alaska. Southeastward, granitic rocks also occur in southeast-trending belts along the Canadian Rocky Mountains and Coast Range.

Isotopic dating of biotite in three Canadian granites 150–250 miles east and southeast of the Romanzof Mountains indicates Paleozoic ages (see table 12) and suggests that the three plutons may be cogenetic. Baadsgaard, Folinsbee, and Lipson (1961, fig. 1, p. 460) tentatively postulated a Paleozoic (probably Middle Devonian) oro-

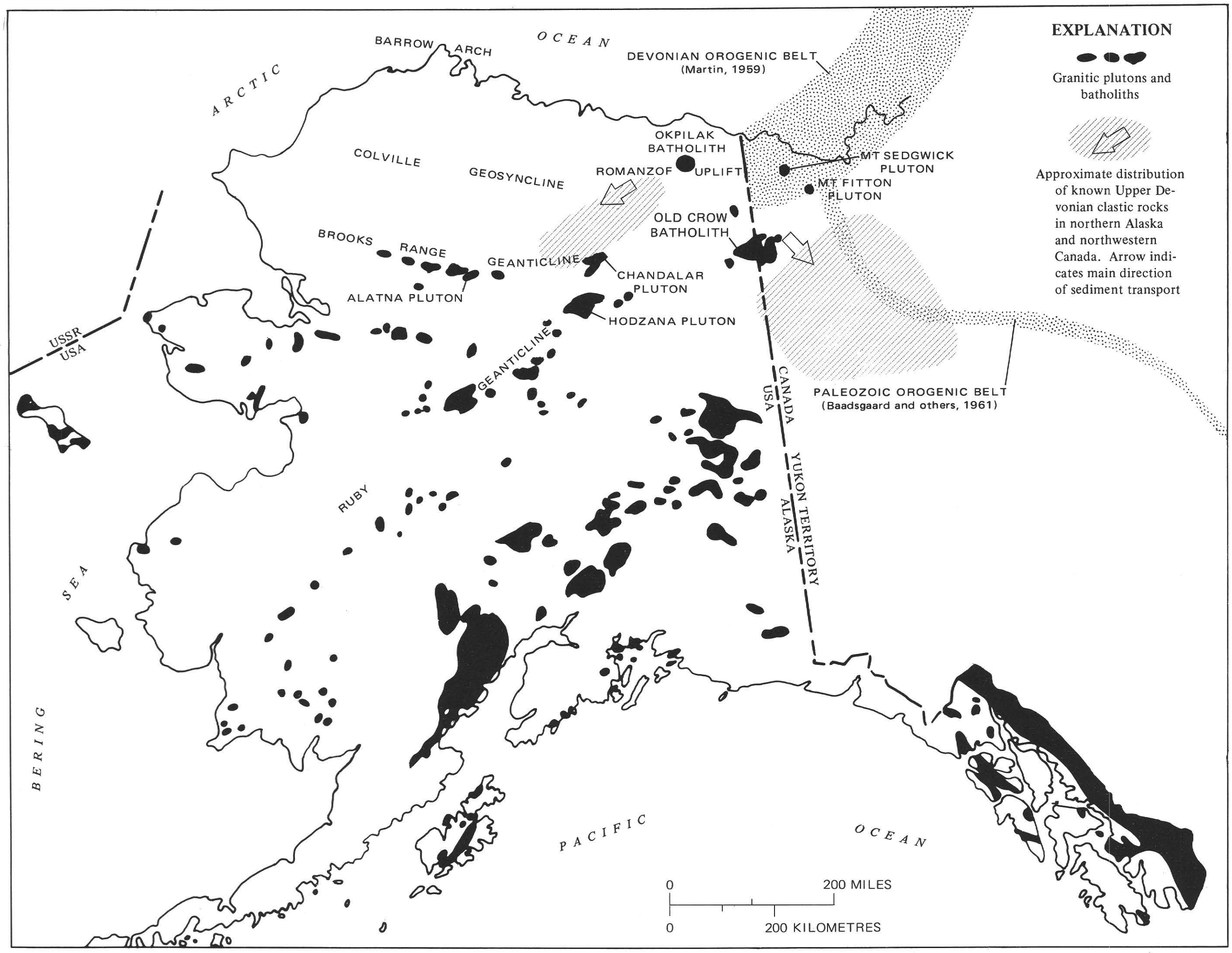


FIGURE 27.—Map of Alaska and northwestern Canada showing selected major tectonic features.

genic belt extending south-southeastward from the Arctic Ocean near the Alaska-Yukon boundary to Montana.

Martin (1961, p. 449) stated that an orogenic maximum occurred in Late Devonian time in northwestern Canada and indicated that the Innuitan orogenic belt of the Canadian Archipelago and northern Greenland extends across the northern fringe of the western Canadian mainland and strikes southwestward and westward toward the Romanzof Mountains area, rather than joining the southwestward-trending belt of Baadsgaard, Folinsbee, and Lipson. Bassett and Stout (1967, p. 730, 746) indicated a trend similar to Martin's in the northern Yukon Territory but extending farther south and encompassing all granitic plutons in the northern Yukon Territory and northeastern Alaska.

If Martin is correct in his westward extension of the Innuitan orogenic belt, then (1) the belt may have extended westward from the Romanzof Mountains area north of the later Brooks Range geanticline, as suggested by Martin (1959, p. 2444); (2) it may have continued in a more southwesterly direction, generally coextensive with the Ruby geanticline; and (3) it may roughly coincide with the later Brooks Range geanticline. Some evidence is suggested below for these possibilities; evidence and interpretations are shown in figure 27. These interpretations are based on the classical concept that the northernmost continental masses and Arctic Ocean basin have maintained virtually the same relative positions since mid-Paleozoic times.

Interpretations of the Devonian sequence described by Brosgé, Dutro, Mangus, and Reiser (1962) in the eastern Brooks Range support the possibility of a positive belt north of the Brooks Range geanticline and may indicate that a Late Devonian orogeny is reflected by outpouring of the Kanayut Conglomerate, which was deposited in an east-northeast-trending basin 50–200 miles southwest of the Romanzof Mountains. In the eastern Brooks Range, thickness and lithologies of the Kanayut suggest a northern or northeastern source area, perhaps in the Romanzof Mountains area or farther north. In the Yukon

Territory, 75 miles southeast of the Romanzof Mountains similar coarse Upper Devonian clastics (Martin, 1959, p. 2442–2443) indicate a source area to the northwest representing the Upper Devonian orogenic belt, which Martin placed in the British and Barn Mountains area, but which could include the Romanzof Mountains area as well. Norris (1967) indicated that these coarsely clastic rocks extend discontinuously in a broad belt eastward into the Canadian Arctic Archipelago; they were derived from north and northwest sources. According to this evidence, an Upper Devonian positive belt might have trended westward from the Arctic Archipelago across northernmost Alaska, perhaps through the Point Barrow area, where a positive structural element, the Barrow arch (Payne, 1955) exists. Pre-Mesozoic rocks in wells drilled in the Barrow arch area include dark argillites similar to the Neruokpuk Formation which are unconformably overlain by Triassic and Jurassic rocks (Collins, 1961; Robinson, 1959), thus indicating a positive area there in late Paleozoic time.

Distribution of granitic plutons in the eastern Brooks Range and Ruby geanticline may suggest that a Paleozoic orogenic belt roughly coincided with the Ruby geanticline, rather than paralleling the present continental margin. Many of the plutons in the Ruby geanticline have not been dated and, until they are, this possibility is speculative. The regional patterns of Late Devonian clastic sedimentation in the eastern Brooks Range and the abnormally thin Kekiktuk, Kayak(?) and Lisburne rocks in the Romanzof Mountains do not preclude such a possibility.

Evidence for Paleozoic and Mesozoic orogenic belts which may have generally coincided with each other along the Brooks Range geanticline trend is inconclusive. A belt of strong negative gravity anomaly across northern Alaska (Woollard and others, 1960), based on scattered control points and high average topography, generally corresponds with the Romanzof uplift and Brooks Range geanticline and agrees with the pattern of granitic pluton distribution in north-eastern Alaska and adjoining Canada. The gravity trends shown are highly generalized, however, and the pattern may be related entirely to Mesozoic and Cenozoic mountain building. Somewhat more detailed gravity data in parts of northern Alaska suggest that the largest gravity gradients are associated with known Mesozoic structures (D. F. Barnes, written commun., 1968), and some granitic plutons along the south half of the Brooks Range are reported as Early Cretaceous in age (Tailleur, 1969).

A very different concept for the tectonic framework of northern Alaska, suggested by Tailleur (1969), involves a variation of Carey's (1958, p. 195–216) postulate for tension rifting of the Arctic Ocean Basin. According to his interpretation, northern Alaska and eastern Siberia are parts of an allochthonous block originally connected with the present Canadian Archipelago. The block has impinged on Alaska by southward scissorslike drifting during Mesozoic and early Cenozoic times, resulting in the Brooks Range orogenic belt. Tailleur considered that granites emplaced in the Brooks Range are related to these movements and are of Mesozoic age whereas Paleozoic granites of similar composition in the adjoining Yukon Territory are in a rifted segment of the Paleozoic Innuitan fold belt of the Canadian Archipelago. According to this concept, the Brooks Range is not directly related to the Paleozoic fold belt, and attempts at temporal correlations of granite plutons in the Brooks Range of those of Paleozoic age in the Yukon Territory from their present spatial relationships are without basis. Tailleur considered time of initial granite emplacement in the Romanzof Mountains to be Cretaceous, a viewpoint I disagree with.

In my opinion, the presence of a Paleozoic orogenic belt with attendant plutonism in northeastern Alaska is established. Perhaps the most reliable date in the northeastern Brooks Range is that of Silurian age from the most recently discovered pluton south of the Jago stock (Reiser, 1970; discussion by Marvin Lanphere in Churkin, 1970, p. G16). Despite numerous potassium-argon Mesozoic determinations (tabel 12), the Paleozoic ages determined by this and other methods support the concept of Paleozoic orogeny. I believe that a mid-Paleozoic (Silurian to Middle Devonian) orogenic belt extended through and north of the Romanzof Mountains along what is now the continental shelf, and extended westward through the Barrow arch. Whether the belt represented one side of the Innuitan fold belt (Tailleur, 1969) or an extension of it as part of a circum-arctic fold belt (Churkin, 1969, 1970) is still unresolved because because sufficiently detailed geological and geophysical data from the Arctic Ocean basin and the bordering continents are not yet available. The tectonic framework of northern Alaska and northwestern Canada is highly complex, and dislocations by post-Paleozoic crustal rifting or transcurrent faulting have probably compounded the complexity. In addition, other types of movements either related to or independent of large-scale rifting may have occurred, such as possible large-scale eastward thrusting in the Seward Peninsula (Sainsbury, 1969) which may have affected major structures as far east as the Romanzof Mountains. These factors make interpretation of earlier Paleozoic trends highly speculative.

ECONOMIC GEOLOGY

Because systematic explorations have only recently been undertaken (Brosgé and others, 1970), mineral resource potential of the Romanzof Mountains is not well known. Some individual prospecting has been carried on at the forks of the Okpilak River. During the present studies, small amounts of mineralization were seen at many localities, mostly in granite and in rocks of the Neruokpuk

Formation. These deposits appear to be mainly associated with fractures, sheared zones, and areas of tactites. Panned concentrate samples were taken in 15 localities in drainages of the Okpilak and Jago Rivers, but no native precious metals were observed. Eleven stream-silt samples were collected for analysis of trace metal content.

Metallic minerals consist mostly of pyrite, with lesser amounts of molybdenite, pyrrhotite, magnetite, arsenopyrite(?), chalcopyrite, chalcocite(?), and galena. Fluorite is sparsely disseminated in some sheared granitic rocks and greisen and it occurs as banded concentrations in tactite.

Previous radiometric and mineralogic studies of panned concentrates and granite bedrock samples from this area have been reported by White (1952). The samples contain a notable percentage of uranium, which appears to be entirely in the biotite and thus can be increased by heavy-mineral concentration.

Pyrite in granitic rocks occurs finely disseminated along narrow linear zones and over broad areas as much as 2,000 feet wide and also in veins intergrown with quartz, or with quartz, tourmaline, topaz, and fluorite. Disseminated pyrite occurrences indicated by highly-ironstained granite commonly coincide with schistose zones, but some areas represent sulfide introduction with accompanying alteration in only mildly fractured granite. The change is shown by the chemical analysis of sample 58ASa60, unaltered granite, and 58ASa61, bleached and pyritized granite from the same vicinity (table 9). The altered granite shows gain in SiO_2, pronounced gains in S, NaO, and TiO_2, pronounced losses in iron oxides and K_2O, and some loss of CaO and Al_2O_3. Comparison of thin sections of samples 60 and 61 shows that microcrystalline quartz has been introduced, probably along fractures. Pyrite occurs as disseminated broken grains, and muscovite with relatively abundant sphene is probably after biotite. Highly sericitized plagioclase (oligoclase-albite?) in the unaltered specimen is in contrast to relatively fresh albite(?) in the altered rock. The main changes are the addition of sulfur and silica and the removal or transfer of iron. Pyrite and (or) marcasite also are disseminated in shale of the Sadlerochit Formation near the Okpilak River and occur more sparsely in all pre-Cretaceous sedimentary rocks.

Some pyrite-quartz veins which crosscut granite show strong crystal parallelism to schistosity or biotite foliation in the adjoining granite; in other places where granite contains equally strong planar elements, pyrite-quartz or quartz veins show no such parallel orientation, and quartz crystal axes lie normal to vein walls. These two types of vein structure suggest two episodes of mineralization, one contemporaneous with strong deformation and the other postdeformational.

Molybdenite occurs as scattered single crystals and crystal aggregates less than half an inch in diameter in relatively fresh granite. It was particularly noted in glacial debris and in a few outcrops in the vicinity of Leffingwell Glacier; elsewhere it is very sparse.

Pyrrhotite and magnetite are locally abundant as fine disseminations and bands less than one-fourth inch wide in dark hornfels and tactite adjoining the granite along Esetuk Glacier and the creek draining Contact Glacier. Mineral associations and textures are described in measured section 12. In the Esetuk Glacier vicinity, magnetite concentrations occur as pods several feet thick in dark tactites, and they affect a compass needle a few feet distant.

Chalcopyrite and galena were found as small grains in sheared quartzose granitic rocks at their contact with Neruokpuk quartzites on the north side of the Jago stock. Chalcopyrite in quartz was tentatively identified in sheared zones parallel to bedding in the lower part of the Neruokpuk Formation along Hubley Creek. Galena, sphalerite(?), and chalcopyrite with pyrite occur at sheared contacts between granite and quartz-monzonite dikes along a tributary of Arey Creek. Here the metallic minerals are in highly deformed pods or stringers of iron-stained vein quartz and schistose rock a few inches in width. Their introduction was concurrent with, or preceded, the shear stress. Galena is so deformed that the cubic mineral cleavage is hardly recognizable.

Purple fluorite occurs in granite as veinlets associated with fine-grained quartz and pyrite and as disseminated small grains in greisen rocks. Tourmaline is a common associate, and the two appear to be contemporaneous. Green fluorite in banded concentrations as much as 4 inches thick was seen with tactite rubble adjoining Esetuk Glacier.

Analyses of stream-silt samples collected in 1957–58, along with 133 others collected in the Romanzof Mountains and adjacent areas, are reported by Brosgé, Reiser, and Estlund (1970). Some samples in the mapped area show anomalous lead, tin, and possibly beryllium values.

The mineral associations and compositional similarities of these granitic rocks and those on the Seward Peninsula (table 9) and other tin-bearing granites suggest that tin and beryllium mineralization in the Romanzof Mountains should be further investigated. Crystals of beryl occur in vuglike cavities and as fracture fillings in epidote tactites along Esetuk Glacier and farther south.

Except for pyrite, none of the ore minerals seem to be widely distributed or traceable for more than a few tens of feet. Large areas in the Romanzof Mountains remain to be explored. Altered carbonate rocks along the west and east margins of the Okpilak batholith might be favorable areas for exploration.

The Shublik Formation may be a potential source of phosphate rock. Two samples from the formation in the Romanzof Mountains area have been analyzed. Patton and Matzko (1959, p. 12) reported 22.0 percent P_2O_5 in limestones of uncertain stratigraphic position, now known to be Shublik, west of the Okpilak River. A sample of limy shale from the east valley wall of the Okpilak gives a value of 4.7 percent P_2O_5. Patton and Matzko reported values as high as 35.8 percent P_2O_5 from the Shublik elsewhere in northeastern Alaska.

Petroleum or gas potential probably does not exist within the mapped area. Possible source rocks that may indicate potential in areas north of the Romanzof Mountains are the organic limestones of the Lisburne Group, organic shales and limestones of the Shublik Formation, and thick black shales of the Kingak Shale. Potential reservoir rocks are those of the Lisburne Group, particularly the coarse crinoidal rocks in the Wahoo Limestone and the lower sandy limestones of the Alapah Limestone. In the Romanzof Mountains area, both of these are capped by relatively impervious rocks, and the top of Lisburne Group is marked by an unconformity. If the clastic components of these rocks were shed from the north, they may coarsen in that direction. Structurally competent Lisburne Group rocks may be highly fractured in the subsurface. The Paleozoic clastic rocks observed in the Romanzof Mountains appear to be relatively tight and impermeable, except for some sandy limestone beds in the Lisburne and Cretaceous sandstones.

SUGGESTIONS FOR FUTURE WORK

The work reported here has established a geologic framework in which future detailed studies can be made. it has:

1. Established the stratigraphic column, at least for Mississippian and younger rocks.
2. Outlined the areas of granitic and associated crystalline rocks, and attempted to establish their time and spatial relationships to their surroundings.
3. Established a plausible areal structural picture.
4. Attempted to fit the area into a larger tectonic framework.

Conversely, it has failed to conclusively answer some of the most basic questions in regard to the area: the age and mode of emplacement of the granitic rocks; the undoubted stratigraphic sequence within the Neruokpuk Formation; the meaning and relative ages of many structural and textural features within the granitic rocks; and possible differences in structural trends resulting from Paleozoic and Mesozoic deformation. Much of the granite and nearly all of the area south of the pluton are not yet mapped or are mapped at small scale (Reiser and Tailleur, 1969).

Future studies in this area might include:

1. Detailed mapping of the western and southeastern interior parts of the Okpilak batholith.
2. Detailed mapping of Neruokpuk Formation rocks south of the pluton and along the Hulahula River to the west.
3. Petrofabric studies in local areas of Mississippian and later rocks and in rocks of the Neruokpuk Formation to determine specific differences in the directional elements of the two sequences.
4. Detailed examination of granite contact zones, particularly those along the west margin of the batholith, to determine possible economic mineral potential.
5. Attempts to date some of the more recent glacial moraines by lichenological studies.
6. Detailed study of the Kekiktuk-Kayak(?) boundary to evaluate the relationships of these two formations.
7. Detailed lithic examination and faunal studies of the Lisburne Group in the area west of the Okpilak River.
8. Reexamination of the Sadlerochit Formation–Lisburne Group contact to evaluate degree of pre-Permian unconformity.
9. Age determinations of the inner parts of the Okpilak batholith and of metamorphic rocks around its periphery.
10. Further examination and sampling of greisen mineralization and granite facies for tin, beryllium, and molybdenum potential.

MEASURED SECTIONS

The following measured sections of sedimentary and metasedimentary rocks are representative of the western Romanzof Mountains area. Thicknesses given are approximate; in some sections, unrecognized structural complications which affect unit thicknesses undoubtedly occur. Description localities are shown on plate 1.

Section 1—Neruokpuk Formation, [along] west side of Jago River between Hubley Creek and creek draining Contact Glacier.

[Measured with altimeter by E. G. Sable, July 25–August 1, 1957]

	Thickness feet
Neruokpuk Formation:	
8. Siltstone, slate, phyllite, and quartzite. Siltstone and quartzite, medium-gray; weathers pale yellowish brown, in part sandy; beds generally 6 in.–3 ft thick; siltstone is calcareous. Phyllite and slate interbedded with above, medium-dark-gray, about 50 percent of section	Unknown
Covered interval	200?
7. Quartzite, with interbedded schist and slate. Quartzite and schist, grayish-green, chloritic, fine- to coarse-grained with scattered subround quartz granules, banded, evenly bedded; beds generally 6 in.–2 ft thick, as much as 5 ft thick. Interbedded medium- to medium-dark-gray quartzite, argillaceous to sandy. Grayish-green chloritic schist. Dark-gray slate. Minor gray calcareous sandstone, very fine grained, in platy 2-in.-thick beds. Resistant unit; quartzite about 75 percent of section	900+
6. Quartzite, with interbedded dark-gray slate and siliceous shale. Quartzite, medium-gray to medium-dark-gray and olive-gray, fine- to coarse-grained, with scattered granules of quartz and	

Neruokpuk Formation—Continued | *Thickness (feet)*

chert; evenly bedded, massive beds 6 in.–7 ft thick, weathers flaggy, blocky, and massive. Interbedded thin quartzite and shale, weathers pale yellowish brown, olive gray, and greenish gray, iron-stained, banded to uniform beds less than 6 in. thick. Massive resistant unit; quartzite about 80 percent of section .... 700±

5. Argillite, siliceous shale, and slate, with interbedded chert. Argillaceous rocks, greenish-gray, pale-olive, and light-gray, with platy parting mostly less than 1 in. thick. Upper part of unit contains higher percentage of chert and cherty argillite, light-gray to grayish-red, in evenly bedded to wavy beds ⅛–1 in. thick alternating with slate and argillite. Argillaceous rocks constitute about 80 percent of unit, chert 20 percent. Milky quartz veins common in upper part of section. Moderately resistant unit; crops out on steep mountain slope. Poorly exposed .... 350±
4. Limestone, medium-dark-gray to dark-gray; weathers light olive gray; sandy, with platy to fissile partings less than 1 in. thick. Contains few ⅛-in.-diameter iron-stained spherical concretions(?). White calcite and pink quartz veins seen in rubble. Poorly resistant unit, crops out on moderately sloping mountain sides. Very poorly exposed ...... 300±
3. Quartzite, medium-gray; weathers moderate yellowish brown; fine to coarse grained with few granules of quartz and dark-gray chert; in part salt-and-pepper texture, in part argillaceous to silty; some interbedded calcareous sandstone. Beds as much as 5 ft thick, evenly bedded, in part banded, mostly massive to blocky; cut by white quartz veins. Very resistant unit but less massive in upper 100 ft; cliff former .... 400±

Fault?

2. Interbedded limestone, phyllite, quartzite, and slate. Limestone, dark-gray to medium-gray, very finely crystalline; shaly, and sandy, soft to well indurated, in part phosphatic(?) and carbonaceous, blocky to fissile. Quartzite, mostly greenish gray; weathers light to moderate brown; in tabular to lenticular beds 1–3 ft thick, commonly interbedded with dark-gray slate in sets of beds as much as 2 ft thick. Micaceous and calcareous phyllite, commonly interbedded with limestone and slate, gray to greenish-gray; in sets of beds as much as 5 ft thick. Interbedded schist, greenish-gray to pale-olive, in part calcareous. Poorly resistant unit; contains few iron-stained zones perhaps along faults; limestone dominant lithology .... 700±
1. Limestone, with minor interbedded slate, phyllite, siltstone, and quartzite; similar to those in preceding units. Limestone, medium-gray to black, in part graphitic; weathers medium light gray to moderate yellowish brown; sandy to shaly with grain size increasing upward in unit; some finely crystalline beds in lower part of unit; tabular beds with blocky, platy, and fissile fracture; some beds finely laminated or alternately fine and coarse grained. Several zones of shear and mineralization parallel to bedding and as much as 30 ft thick which contain veins and lenses of milky quartz and calcite, disseminated pyrite, and green asbestiform amphibole(?). Moderately resistant unit; contains some massive cliff-forming limestone sets of beds as much as 90 ft thick. (See section 2 for detailed description of this unit) .... 1,000+

Base of Section
Total (incomplete) .... 4,350±

Section 2—Neruokpuk Formation, detailed description of unit 1 in measured section 1 and of underlying rocks

[Measured with altimeter and tape by E. G. Sable, July 1957]

	Thickness (feet)
Glacial debris, Pleistocene.	
Neruokpuk Formation, unit 1 of measured section 1:	
35. Quartzite, greenish-gray; weathers light olive brown to light and moderate brown; fine grained, even textured, massive, lenticular, very hard	8±
34. Limestone, dark-gray, fragmental, fine- to medium-grained; with even beds ⅛–½ in. thick, soft, banded; weathers platy	20
33. Limestone, dark-gray, sandy, fine- to medium-grained; platy, even bedded, and even textured in upper part; textural fine- and medium-grained banding in lower part. Mostly rubble covered	130±
32. Limestone as in unit 33; beds less than 2 in. thick	65
31. Slate, medium-dark-gray	3
30. Limestone, medium-gray to medium-dark-gray; sandy beds ¼–½ in. thick of alternating fine- to coarse-grained limestone; includes 5-ft-thick lenticular siliceous mass that contains irregular veins and masses of white quartz, and green asbestiform mineral (amphibole?)	90±
29. Phyllite and slate, iron-stained; contains numerous disseminated pyrite crystals. Poorly exposed	40
28. Limestone, medium-dark-gray, sandy, fine- to medium-grained; contains small lenses of white quartz and calcite. Massive and resistant; lower 5 ft has contorted bedding	45±
27. Limestone and mineralized limestone, contorted, highly iron stained. Mostly calcite with distorted calcite crystals 2–6 in. in diameter, pyrite crystals as much as ¾ in. in diameter, and green mineral, probably chlorite. Small lenses and veins of white quartz throughout; highly resistant	15±
26. Limestone, mostly medium gray to medium dark gray, sandy, alternating medium- and coarse-grained beds 1–4 in. thick; in part dark gray, finely laminated, fissile. Contains quartz and calcite lenses and small drag folds in lower 5 ft of unit. Massive and resistant	75±
25. Fault(?). Dark-gray slate and phyllite in upper few feet; remainder is slate and limestone as in unit 26. Mostly covered	35±
24. Limestone, dark-gray, platy, contains few quartz and calcite veins as much as 6 in. thick parallel to bedding. Sheared-appearing phyllite and slate in upper 4 ft. Poorly exposed	19±
23. Sheared siliceous limestone and phyllite, light- to medium-gray, mostly very fine grained. Irregular quartz and calcite veins with disseminations and concentrations of pyrite crystals. Massive and iron-stained; mineralized	8±
22. Limestone, dark-gray to black, platy to fissile, soft; beds average 2 in. in thickness, as much as 6 in.	

Neruokpuk Formation, unit 1 of measured section 1—Continued

	Thickness (feet)
thick. Upper few feet appears sheared, has white efflorescence and thin quartz lenses along bedding planes. Grades downward into 21	7
21. Slate, gray, soft, in part iron stained	4
20. Limestone, dark-gray to black; weathers olive gray; bituminous or graphitic; platy to fissile; beds 1-10 in. thick, laminated to uniform; generally finely crystalline. White efflorescence ("phosphate bloom"?) on some surfaces. Scattered thin quartz and calcite veins	43
19. Limestone, dark-gray; weathers light gray to yellowish brown; medium crystalline; massive	8
18. Covered interval	25
17. Limestone, dark-gray, finely crystalline, massive; quartz veinlets along joints	5±
16. Mostly covered. Float of platy limestone similar to that in 17	40
15. Limestone, medium-gray to dark-gray, soft; in massive to platy beds that average 2 in. in thickness but are as much as 1½ ft thick in upper part. Thinner bedded and softer in lower 20 ft	90
14. Mineralized zone along contorted bedding. Mostly platy limestone alternating with 1- to 3-ft thick iron-stained layers with lenses of milky quartz and calcite with disseminated pyrite. Upper 2 ft is iron-stained micaceous dark-gray slate	25±
13. Limestone, medium-gray to medium-dark-gray, platy to blocky; thin iron-stained calcite veins and lenses. Partly covered	28
12. Limestone, platy, resistant; otherwise like 13	25±
11. Covered. Float of limestone and siltstone	20
10. Limestone and quartzitic siltstone interbedded. Limestone, medium-dark-gray; in part schistose; iron stained. Siltstone, light-gray; contains disseminated pyrite. Beds mostly 2 in. thick, as much as 1 ft thick	10
9. Limestone, medium-dark-gray, laminated, platy; beds 1/16-½ in. thick	20
8. Covered; float of dark-gray soft limy shale and fissile limestone	18
7. Limestone as in 8, but with some medium crystalline soft limestone in beds as much as 2 ft thick	47
6. Limestone as in 8, but with white efflorescence; in part iron stained, and with calcite veinlets	10
5. Limestone, quartzite, and chert. Limestone, 75 percent; medium dark gray, weathers pale yellow brown; finely crystalline, platy; laminated, with calcite veins roughly parallel to bedding. Quartzite, 15 percent; gray; in irregular beds and lenses as much as 1½ in. thick. Chert, 10 percent; novaculitic, in wavy beds less than 1 in. thick	7
4. Limestone, as in 5; soft; beds ⅛-½ in. thick. Lower 5 ft contorted	75
3. Covered. Float of phyllite and slate, medium light gray, micaceous	15±
Base of Section.	
Measured unit 1	1,015±
2. Alteration zone, hornfels and tactite. Hornfels, mostly dark greenish gray, in part finely banded. Dark iron staining with metallic luster; contains visible disseminated pyrite, magnetite, and pyrrhotite. Estimated maximum thickness	500±

Neruokpuk Formation, below unit 1 of measured section 1

	Thickness (feet)
1. Quartz-muscovite schist, light-gray to greenish-gray; grades downward into iron-stained granite. Estimated thickness	50+
Base of Section.	
Total	550+

NOTE.—Although carbonate rocks in this measured section are described as limestones, thin sections indicate that they are fine- to medium-crystalline impure marbles in which carbonate grains are generally elongate and parallel.

Section 3—Neruokpuk Formation, phyllite-quartzite unit, exposed on east valley wall of Old Man Creek about one-quarter mile south of its junction with Slippery Creek

[Measured by R. S. Bunnell, July 26, 1958]

	Thickness (feet)
Katakturuk Dolomite.	
Neruokpuk Formation:	
Phyllite-quartzite unit:	
10. Covered interval. Vertical distance of about 100 ft, heavings of dark-gray slate. Exposures of strata several hundred yards away from, but probably equivalent to, rocks in this covered interval are composed of 90 percent slate with interbedded argillite and quartzite. Slate is dark gray to medium dark gray, weathers dusky gray brown to light brown, is in part banded with laminations ¼-1 in. thick. Quartzite is medium dark to dark gray, weathers light brown, occurs in beds as much as 2½ ft thick. Gray argillites weather dark brown	100±
9. Quartzite, medium-gray; weathers light gray; fine grained, slightly micaceous. Occurs as one massive bed. Black to dusky-red iron staining on surfaces	10
8. Quartzite, dark-gray; weathers medium dark gray to dark brown; fine-grained massive unit; slightly banded. Yellowish-orange iron staining	6
7. Shale and shaly quartzite interbedded, dark-gray; beds average about 3 in. in thickness. Yellowish-orange and dusky-red iron staining	8
6. Quartzite, very light gray to almost white; fine grained in one massive bed. Appears to be almost pure quartz in contrast to most quartzite beds in this sequence. Very minor yellowish-orange iron staining	8
5. Slate, dark-gray; weathers olive gray; thin bedded, 4-6 in. average. Much yellow sulfurlike "bloom" (jarosite?), some dusky-red iron staining	30
4. Quartzite, white, very fine grained, massive; more prominent than unit 5. Almost pure quartz. Prominent joints with yellowish-orange iron staining	8
3. Quartzite, dark-gray to medium-dark-gray; weathers light gray to light brown; shaly, slightly micaceous, thin bedded with beds averaging 3-4 in. thick. Patches of yellowish-orange iron staining	10
2. Quartzite, medium-dark-gray; weathers light brown; fine grained; massive beds average 6-8 ft in thickness. Much dusky-red and yellowish-orange iron staining	40

Neruokpuk Formation—Continued
Phyllite-quartzite unit—Continued

	Thickness (feet)
1. Shale and interbedded quartzite. Shale, 90 percent of unit; dark gray, weathers olive gray. Quartzite, dark gray, weathers light gray; fine grained. Slight amount of yellowish-orange iron staining	20
Base of Section.	
Measured phyllite-quartzite unit (incomplete)	240±

Section 4—Katakturuk Dolomite, exposed on south valley wall of Slippery Creek about one-quarter mile east of its junction with Old Man Creek

[Measured with tape and in part estimated by E. G. Sable, August 1, 1958]

	Thickness (feet)
Kayak(?) Shale:	
8. Covered interval with heavings of shale and slate-Not measured	
Katakturuk Dolomite:	
7. Breccia, angular to subround fragments of medium- to dark-gray carbonate rock in medium-light-gray, very fine grained to fine-grained matrix; siliceous; weathers yellowish gray to light grayish orange	40±
6. Covered. Float of black siliceous shale and slates and fine-grained sandstone. Black mud	70±
5. Siliceous carbonate rock, intraformational breccia, medium-light-gray to light-gray, very fine grained. Largely carbonate breccia with angular to subround fragments; weathers light brown and yellowish orange	80±

Katakturuk Dolomite—Continued

	Thickness (feet)
4. Siliceous carbonate rock, medium-gray to medium-dark-gray; weathers black with some beds of yellowish orange; very massive	10
3. Siliceous carbonate rock, dark-gray to grayish-black, very fine grained, in part laminated; small amount of phosphate "bloom." Contains a few angular breccia fragments of the same rock	65±
2. Siliceous carbonate rock, massive and uniform with irregular fragments of laminated siliceous carbonate rock as much as 6 in. long	6
1. Siliceous carbonate rock, medium-dark-gray; weathers medium gray with some grayish orange and dark yellowish orange. Laminated; in part brecciated	55
Measured Katakturuk Dolomite (incomplete)	326±

Section 5—Sadlerochit Formation, Lisburne Group, and Kayak(?) Shale and Kekiktuk Conglomerate undivided, exposed on east wall of Okpilak River valley, about 1.7 miles south of Okpilak Lake

[Recorded thicknesses of the Ivishak Member are excessive because of faulting and probable shale flowage, unrecognized during section measurement. Measured with altimeter and tape and in part estimated by E. G. Sable and G. R. Kunkle, August 12-13, 1957, and E. G. Sable and R. S. Bunnell, June 14, 1958]

	Thickness (feet)
Sadlerochit Formation:	
Ivishak Member:	
65. Quartzite and interbedded slate. Quartzite, about 80 percent of unit; medium gray to grayish red, weathers olive brown to red, fine to medium grained; clean, even bedded; blocky to massive, in beds as much as 2 ft thick. Slate, medium-gray, dark-gray, and grayish-brown; in beds mostly less than 1 ft thick, increases in abundance upward. Veins of milky quartz in quartzite; some contorted bedding. Thickness estimated	200±

Sadlerochit Formation—Continued
Ivishak Member—Continued

	Thickness (feet)
64. Quartzite and minor interbedded slate, similar to unit 65 but somewhat more schistose. Contorted bedding in middle of unit. Estimated thickness	350±
63. Quartzite and slate, as in unit 64, but with higher percentage of slate. Quartzite, very fine grained to silty; one massive bed of light-gray quartzite in uppermost part; much quartzite with alternating light- and medium-gray laminated bands ½–1 in. thick. Poorly exposed	195
62. Quartzite and slate as in unit 65. Quartzite uniformly fine grained, schistose; slate about 50 percent of unit. Partly talus covered	155
61. Quartzite, dark-gray to medium-gray, weathers olive gray and iron stained; very fine to fine grained, argillaceous and slaty; beds 2–3 ft thick with thinner argillaceous interbeds. Upper part of unit is schistose	180±
60. Slate, dark-gray to medium-gray; weathers light gray to brown; clay to silt size. Mostly rubble	80
59. Quartzite and interbedded slate. Quartzite, about 70 percent of unit; dark gray to medium gray; in part laminated, thin bedded; contains relict cavities from pyrite cubes as much as ¾ in. in diameter; iron stained. Quartz veining prominent	60
58. Slate, medium-gray to dark-gray	25
57. Quartzite, as in unit 59, with few slate interbeds. Scattered pyrite cubes as much as ¼ in. in diameter	15
56. Mostly talus covered; rubble of mostly slate and slaty quartzite	30
Total Ivishak Member (incomplete)	1,290±
Echooka Member:	
55. Quartzite, greenish-gray (5*GY* G/1); weathers dark yellowish orange and moderate reddish brown; fine to very fine grained; beds as much as 5 ft thick, with blocky fracture and prominent joints; iron stained. One 2-ft-thick bed of dark-gray slate 10 ft above base of unit. Unit grades downward into unit 54. Estimated thickness	80±
54. Quartzite, medium-gray to dark-gray; weathers yellowish gray and iron stained; fine to very fine grained; beds 1–2 ft thick. Limonite grains comprise about 15–20 percent of detrital fraction	35
53. Slate, medium-gray; weathers light gray; mostly clay-size grains. Calcite coatings on joint surfaces. Partly talus covered	40
52. Quartzite, dark-gray to medium-gray; weathers olive gray to yellowish orange and reddish gray; very fine to fine grained with few beds medium to coarse grained; beds 2–3 ft thick with 1- to 3-in.-thick slaty interbeds	42
51. Quartzite, as in unit 52 but with 5–10 percent round to subround, 1- to 3-in.-diameter pebbles of black chert	3
50. Talus covered; possible concealed fault	10
Total, Echooka Member	210+
Total, Sadlerochit Formation (incomplete)	1,500+
Lisburne Group:	
Wahoo Limestone:	
49. Limestone, medium-gray, very fine grained to silty; platy to small blocky fragments. Partly covered by rubble	10?

	Thickness (feet)
Lisburne Group—Continued	
Wahoo Limestone—Continued	
48. Limestone, medium-gray, very fine grained, silty; blocky; weathers in small fragments	10
47. Limestone, light-gray to medium-gray; weathers light gray to white; medium to coarse grained; crinoidal biohermal bed; crinoid rings and columnals make up about 40 percent of unit, cemented by very fine grained calcite. Beds well consolidated to very friable, weather in small fragments, with crinoid impressions and some subround fragments of dolomite(?) that weather light colored in uppermost part which is mainly calcilutite	90
46. Limestone, medium-gray; very fine to very coarse calcarenite. Local concentrations of crinoidal debris along bedding. Massive unit, weathers to relatively small fragments	105±
Total Wahoo Limestone	215±
Alapah Limestone, dark carbonate unit:	
45. Dolomite, olive-gray to medium-light-gray; weathers grayish orange; fine grained, saccharoidal texture; beds 2–3 in. thick	10
44. Limestone and dolomite or silicified limestone, medium-dark-gray to dark-gray, very finely crystalline to calcilutite, fractures in small platy fragments	60±
43. Limestone, dark-gray, very finely crystalline; contains 3-in.- to 1-ft-thick lenses of white to light-gray chert parallel to bedding. Limestone makes up about 70 percent of unit	7
42. Limestone, dark-gray, very finely crystalline to lithographic, in part probably silicified. 4-in.-thick nodular black chert lens within unit	3.5
41. Dolomite and interbedded limestone. Dolomite, about 60 percent of unit; light to medium gray; fine grained. Limestone, medium-dark- to dark-gray; very finely crystalline; dense, breaks with conchoidal fracture. Grades downward into unit 40	75±
40. Limestone, dark-gray, very finely crystalline	3
39. Limestone, light-gray to white; weathers light yellowish gray; sandy, with dark-gray argillaceous grains as much as 1/16 in. in diameter	3.5
38. Limestone with minor chert interbeds. Limestone, medium-dark-gray to dark-gray; sandy, very fine, medium grained to finely crystalline. Chert, dark-gray; in lenses less than 1 ft thick; about 5 percent of unit. Calcite lenses and earth hematitic zones about ⅛ in. thick, roughly parallel to bedding but irregular. Estimated thickness	70±
37. Slate, dark-gray, micaceous, fissile. Contains numerous calcite veins	2.5
36. Dolomite and interbedded limestone. Dolomite, dark-gray; weathers dark orange; finely crystalline. Limestone calcilutite type. Resistant unit with beds as much as 5 ft thick. Estimated thickness	55±
35. Limestone, dark-gray, very finely crystalline to silty, soft; emits strong organic odor from fresh fracture surfaces; some fissile parting. Few scattered round to subround pebbles of light-gray sandy limestone. White efflorescence on some surfaces. Grades downward into unit 34	10
34. Dolomite, medium-gray, fine-grained; saccharoidal texture	9
Lisburne Group—Continued	
Alapah Limestone, dark carbonate unit—Continued	
33. Limestone, medium-gray; finely crystalline to sandy; dense; massive. Contains about 25 percent medium-dark-gray chert nodules and lenses as much as 4 in. thick. Earthy hematite associated with some chert lenses. Irregular contact with unit 32	3.5
32. Dolomite, medium-gray to medium-dark-gray; weathers dark orange; sandy, fine to very fine grained	4±
Total dark carbonate unit	315±
Alapah Limestone, sandy limestone unit:	
NOTE: Units 31–29 form a massive resistant section.	
31. Limestone, medium-dark-gray, finely crystalline; contains about 5 percent crinoid rings and bryozoan(?) fragments. Minor lenses of light- to dark-gray, white-weathering chert	5
30. Limestone and interbedded beds and nodules of white chert. Limestone, medium- to light-gray, weathers white to light gray; sandy, massive, in part friable, in beds 1–10 ft thick. Chert lenses as much as 4 in. thick make up about 5 percent of unit	48±
29. Limestone, medium- to light-gray; sandy, with about 40 percent bioclastic limestone containing abundant crinoidal debris and granule-sized calcite grains. Contains less than 10 percent white chert in beds and lenses as much as 6 in. thick and spheroidal cherty concretionlike bodies as much as 3 in. in diameter alined along bedding planes	12
28. Sandstone, light-gray; weathers medium dark gray; highly calcareous; platy to blocky, parting 2–4 in., evenly bedded. Upper 20 ft poorly exposed; contains about 5 percent ellipsoidal white chert nodules or concretions 2–3 in. in diameter	30
27. Mostly talus covered. Limestone, light-gray, sandy	30
26. Limestone, light- to medium-gray, sandy, fine-grained, blocky. Contains a few lenses of sandy white limestone	25
25. Limestone rubble, light-gray to medium-dark-gray, fine- to medium-grained; contains some lithographic types	50
24. Limestone, similar to unit 23 but without chert	5
23. Limestone, white to medium-gray and yellowish-gray; weathers medium gray, sandy, friable to well consolidated; platy to blocky; contains irregular 2- to 6-in.-diameter white chert nodules at top of unit	5
22. Limestone, white to medium-gray, sandy, very fine grained, clean, friable	1.5
21. Limestone, medium-gray; weathers dark yellowish orange; sandy, fine grained, blocky to massive; beds 4 in. to 4 ft thick; emits organic odor from freshly fractured surfaces. Contains crinoid rings, small calcite crystals, and travertine on surfaces. Estimated thickness	28
Total sandy limestone unit	240±
Total Alapah Limestone	555±
Total Lisburne Group	770±

NOTE.—Possible high-angle fault below unit 21.

Top of section. Rubble of Lisburne Group.

Kayak(?) Shale and Kekiktuk Conglomerate undivided:

	Thickness (feet)
20. Covered. Scattered rubble and talus of Lisburne Group and Kayak(?) Shale	10±
19. Quartzite, medium-light-gray to medium-gray; medium to coarse grained with some granule-sized grains; quartz grains subangular, clear, moderately well sorted in quartzose, micaceous, and partly carbonate matrix. Banded to uniform in appearance. Massive unit	15
18. Interbedded quartzite and slate. Quartzite 70 percent of unit and similar to unit 2. Slate, medium-gray; in part finely laminated; contains few quartz granules. Poorly exposed	22
17. Schistose quartzite and quartzitic conglomerate, medium-light-gray; granules and small pebbles of quartz and chert(?) as much as ¾ in. in diameter make up 40–60 percent of unit. Matrix quartzose, micaceous, in part iron stained	7
16. Quartzite and phyllitic slate, interbedded. Slate, about 30 percent of unit; medium light gray to light grayish green; beds less than 3 ft thick; contains quartz granules. Quartzite beds less than 6 ft thick, micaceous. Grades downward into unit 15	20
15. Phyllite and slate, medium-gray, soft; in part finely laminated; interbedded with few 1- to 1½-ft-thick beds of schistose quartzite	15±
14. Schistose quartzitic granule conglomerate, medium-light-gray; highly micaceous, contains about 30 percent quartz granules; massive	12
13. Phyllitic slate, medium-gray	2
12. Schistose quartzose sandstone and quartzite, interbedded and intergraded with gray to greenish-gray phyllitic slate. Quartzite, light-medium-gray; contains subround to subangular clear and milky quartz granules and pebbles as much as ⅜ in. in diameter concentrated in beds as much as 3 ft thick. Low porosity	25±
11. Covered. Talus of quartzite and slate	65±
10. Quartzite, light to very light gray; weathers light brown to grayish orange; evenly bedded, well sorted, fine-grained to granule-sized subround to subangular quartz grains. Varying admixture of light micaceous matrix	12
9. Quartzite, slate, small amount of gray, very finely crystalline limestone; partly rubble covered	127±
8. Sandstone and granule conglomerate, medium-dark-gray; fine to coarse grained with few granules; subround to round, well-sorted quartzose grains. Micaceous matrix; massive unit	12
7. Slate, dark-gray, micaceous, silty	1
6. Sandstone, medium-dark-gray, fine- to coarse-grained, carbonaceous, quartzose; with thin lenses of granule conglomerate. Massive unit	4
5. Sandstone and slate as in units 6 and 7, interbedded.	3
4. Slate, black, carbonaceous; with macerated plant fragments	2
3. Sandstone, medium-gray, massive, iron stained	3
2. Interbedded sandstone and slate as in units 7 and 8. Sandstone beds and lenses as much as 3 ft thick make up 60 percent of unit. Slate contains micaceous flattened and distorted plant impressions. Some concentrations of hematite along slate bedding	16

Kayak(?) Shale and Kekiktuk Conglomerate undivided—Continued

	Thickness (feet)
1. Covered. Estimated thickness	50
Total Kayak(?) Shale and Kekiktuk Conglomerate undivided	423±

Schist and schistose mafic igneous rock.

Section 6—Kayak(?) Shale and Kekiktuk Conglomerate undivided, exposed on west side of Old Man Creek at its junction with Slippery Creek

[Measured by altimeter and tape by R. S. Bunnell, July 27, 1958]

Lisburne Group, Alapah Limestone, scattered fragments— Not measured

Kayak(?) Shale and Kekiktuk Conglomerate undivided:

	Thickness (feet)
11. Limestone, black to medium-dark-gray, shaly, interbedded with calcareous black slate; limestone weathers blocky to slabby. Toward top of the outcrop, shaly limestone grades into fairly clean medium-dark-gray limestone, probably of the Lisburne Group	12
10. Slate, black, silty, slightly calcareous; yellowish-orange iron staining	3
9. Quartzite and interbedded black slate. Quartzite, about 50 percent of unit; weathers dark gray; medium to coarse grained. A 1-ft-thick bed of dark-gray limestone with minor medium-grained quartz occurs at top of unit	12
8. Shale, black, very thin bedded	3
7. Quartzite, medium-light-gray to black, coarse-grained, slightly micaceous; numerous quartz veinlets	3
6. Quartzite, medium-gray; weathers light brown; fine grained; much yellowish-orange iron staining	1
5. Slate, black, weathers dark gray; very thin bedded, silty	3
4. Interbedded quartzite and slate. Quartzite, 70 percent of unit; medium gray to black, ranges from fine to coarse grained, slightly silty and micaceous in beds as much as 3 ft thick averaging 18 in. Slate, dark-gray to black, weathers olive gray; very thin bedded, sets of beds as much as 3 ft thick, but averaging 6–8 in. Entire sequence is mottled with patches of yellowish-orange, dusky-red, and yellowish-green staining	60
3. Conglomerate, medium-gray; subround to subangular pebbles and cobbles of quartz and quartzite as much as 3 in. in diameter, averaging ¼ in. Matrix of fine-grained quartz and black carbonaceous material	4
2. Covered	6
1. Cobble conglomerate, in three beds averaging 18 in. in thickness; quartzite cobbles as much as 4 in. in diameter, average 2 in., interbedded with fine- to coarse-grained, medium- to dark-gray quartzites and black slates. Overlies 6-ft-thick covered interval above rubble of Katakturuk Dolomite	12
Total Kayak(?) Shale and Kekiktuk Conglomerate undivided	119

Section 7—Lisburne Group, exposed on mountainside 1 mile southeast of junction of Old Man and Slippery Creeks

[Measured with altimeter and tape by E. G. Sable, July 31, 1958]

Sadlerochit Formation, rubble and outcrop of iron-stained sandstone ... Not measured

Lisburne Group:	Thickness (feet)
Wahoo Limestone:	
31. Limestone, medium-light-gray, predominantly coarse grained, crinoidal, platy to massive, generally friable, some sublithographic limestone; in part green, with crinoid stem segments and bryozoan fragments. Poorly preserved spiriferoid brachiopods near top. Uppermost bed is a finely crystalline medium-dark-gray limestone	53
30. Limestone, medium-dark-gray; weathers yellowish orange and yellowish brown; sublithographic; weathers as small angular fragments	2.5
29. Limestone, medium-gray; with numerous crinoid stem fragments in fine-grained cement; mostly well indurated but friable in part; mostly irregular platy bedding fracture. Grades downward into underlying unit	50±
28. Limestone, medium-dark-gray; weathers medium gray; fine to medium crystalline; contains thin coquinoid bed of crinoid and bryozoan remains and shell fragments about 5 ft above base. Poorly exposed	40
Total Wahoo Limestone	145±
Alapah Limestone, dark carbonate unit:	
27. Covered	5
Dolomite, weathers orange; blocky	10
26. Dolomite, medium-gray to dark-gray; weathers medium light gray; very fine grained; in part finely crossbedded	30
25. Dolomite, as in unit 24 but contains about 15 percent black chert in irregular beds as much as 5 in. thick	15
24. Dolomite, dark-gray; weathers medium gray to medium light gray; laminated in upper part; numerous calcite-quartz nodulelike bodies and quartz veins	47±
23. Limestone, dark-gray; weathers light gray; blocky fracture; contains silicified shell-like bodies with calcite interiors	12
22. Limestone, as in unit 21, but blocky and with alternations of very fine to coarse-grained layers near base	22
21. Limestone, dark-gray, argillaceous to finely crystalline; scattered crinoidal debris, platy; few chert nodules. Crinoidal debris in about 10 percent of unit	62±
Total dark carbonate unit	203
Alapah Limestone, sandy limestone unit:	
20. Limestone, medium-gray, fine- to medium-crystalline to coarse-grained, crinoidal; interbedded with cherty limestone as much as 6 in. thick; chert is light gray to dark gray, bedded appearing. Styolite partings with reddish hematitic(?) coatings prominent	4
19. Limestone, medium-dark-gray, sandy to silty; with very fine grained carbonate matrix; minor black chert; platy irregular parting in upper 5 ft. Crinoidal bed about 20 ft above base. Dolomitic beds in lower part of unit	55
18. Dolomite, blocky fracture	10±
17. Limestone, sandy with few black chert nodules. Poorly exposed	15±

Lisburne Group—Continued	Thickness (feet)
Alapah Limestone, sandy limestone unit—Continued	
16. Limestone and interbedded dolomite, blocky; white calcite "nodules" about 1–3 in. in diameter with silicified exteriors	12
15. Covered	10±
16. Limestone and interbedded dolomite, sandy, very fine to fine-grained; blocky fracture. Poorly exposed	30±
13. Dolomite, light-gray; weathers grayish orange; very fine to fine grained	10
12. Covered	5
11. Limestone, platy, fine-grained	1
10. Limestone, massive; dark-gray chert lenses as much as 2 ft in length	5
9. Limestone, medium-dark-gray to dark-gray; crinoidal; platy	1
8. Limestone, medium-dark-gray to dark-gray, crinoidal, massive, with crinoidal columnals as much as 3/8 in. in diameter and scattered spherical to ellipsoidal black chert nodules and lenses as much as 6 in. thick	5
7. Limestone, medium-dark-gray to dark-gray; abundant crinoid columnals; wavy bedding	4.5
6. Limestone, medium-dark-gray, medium-grained, sandy, massive, scattered crinoid stem segments, bryozoan fragments and small horn corals in lower 3 ft of unit	10
5. Limestone, as in unit 3, with irregular white quartz inclusions 1/8–2 in. in diameter; minor dolomite in float	25±
4. Limestone, medium-light-gray, sandy, medium-to coarse-grained; blocky to platy, with 2–18-in. partings	25±
3. Talus and scattered outcrops of limestone, medium-dark-gray, very fine to medium-grained, some coarse grained; in part sandy; black chert nodules and beds as much as 3 in. thick and some concretionary-appearing chert	50±
2 Limestone, grayish-orange, sublithographic to finely crystalline, massive; light-gray chert nodules in lower part, black chert nodules in upper part of unit	12
1. Limestone talus and rubble, medium-dark-gray to dark-gray, sandy, silty, and argillaceous. Black chert nodules and concretionlike bodies in middle part; few large productid(?) shell outlines in lower part; rubble of black, soft, phosphatic limestone in lowermost part of unit	70+
Total sandy limestone unit	359+
Total Alapah Limestone	562+
Total Lisburne Group	707+
Kayak(?) Shale, heavings of black shale, mud, and phosphatic (?) limestone	Not measured

Section 8—Lisburne Group, exposed on west valley wall of Old Man Creek about 3.5 miles south of its junction with Slippery Creek

[Measured with altimeter and tape by R. S. Bunnell, July 22, 1958]

	Thickness (feet)
Sadlerochit Formation, Echooka Member	Not measured
Lisburne Group:	
Wahoo Limestone:	
17. Limestone medium-light-gray; weathers very light gray; coarse-grained crinoid fragments; thick bedded, breaks into platy fragments	120

Lisburne Group—Continued Wahoo Limestone—Continued	Thickness (feet)
16. Limestone, dark-gray; weathers medium gray; thick bedded, beds 6–8 ft thick; massive. Crinoid fragments in the upper 10 ft grading up to the bioclastic beds above	50
Total Wahoo Limestone	170
Alapah Limestone, dark carbonate unit:	
15. Dolomite, medium-gray to medium-dark gray; weathers medium dark gray; slabby	25
14. Dolomite, dark-gray to almost black; weathers medium dark gray; silty; slabby. Some dark-gray round and elongate chert nodules	45
13. Limestone and dolomitic limestone. Limestone, about 90 percent of unit; medium dark gray to dark gray to black, weathers medium gray to medium dark gray; beds 2–3 ft thick, 30 percent of beds sandy or silty and break into slabby fragments; remaining beds weather into blocky fragments. Dolomitic limestone weathers orangish gray. Some light- to dark-gray, elongate chert nodules	75
12. Limestone, medium-dark-gray; weathers medium gray; partly bioclastic; blocky. Much light-gray chert	13
11. Covered	10
10. Limestone, medium-dark-gray to dark-gray, sandy; beds average 2–3 ft in thickness; several thin dolomite beds in middle part. Some dark-gray chert nodules, some crinoid fragments	40
9. Dolomite, dark-gray; weathers orangish gray; silty, slabby	8
Total dark carbonate unit	216
Alapah Limestone, sandy limestone unit:	
8. Limestone, medium-gray to medium-dark-gray, sandy; weathers to light gray and orangish gray, massive, thick bedded. Contains a few contorted and silicified fossils	48
7. Limestone, dark-gray, very fine grained, almost lithographic	3
6. Covered	15
5. Limestone, medium-gray to medium-dark-gray; weathers medium gray with patches of orangish gray; sandy, thick bedded with beds 8–10 ft thick, blocky, massive	85
4. Dolomite, dark-gray; weathers orangish gray	5
3. Limestone, medium-dark-gray, sandy, silty; beds 4–5 ft thick. Contains contorted and silicified fossils, and round and elongate chert nodules. Crinoid rings and horn corals common in lower part	40
Total sandy limestone unit	196
Total Alapah Limestone	412
Total Lisburne Group	582
(Kayak(?) Shale:	
2. Covered	10
1. Limestone, black, shaly, probably phosphatic	5
Total Kayak(?) Shale (incomplete)	15

Section 9—Sadlerochit Formation and Lisburne Group, exposed on east wall of Okpilak River valley, 1.5 miles south of Okpilak Lake

[Measured with altimeter and tape by E. G. Sable, June 24, 1958]

Sadlerochit Formation (incomplete): Ivishak Member, shale unit (incomplete):	Thickness (feet)
26. Slate rubble, medium-dark-gray. Probable fault above this	8+
25. Slate, medium-dark-gray in upper half of unit; dark gray in lower half; clay to silt size	12±
24. Slate rubble; as in unit 25 with scattered clay ironstone nodules to ¼ in. in diameter which increase in abundance downward. Unit grades downward into unit 23	10±
Total Ivishak Member (incomplete)	30±
Echooka Member:	
23. Quartzite, medium-dark-gray, silty; in part iron stained	15±
22. Conglomeratic quartzite; black round recrystallized chert pebbles and silty ironstone lenses in silty matrix	1
21. Slate and phyllite, medium-dark-gray, silty to fine-grained; in part sandy, micaceous, with highly iron stained surfaces. Cut by quartz-limonite veins	8
20. Silty ironstone, dark-gray; weathers grayish red; siliceous; in lenslike forms as much as 2 ft long; scattered pyrite cubes	1
19. Slate and phyllite as in unit 21. Minor amount of dark-gray chert. Poorly exposed	41±
18. Quartzite and minor interbedded slate. Quartzite, dark-gray, silty to very fine grained; beds average about 1 ft in thickness, as much as 5 ft thick. Scattered angular to round siliceous nodules (pebbles?) of finely granular dark-gray silica ½–4 in. in diameter; few scattered brachiopod molds. Resistant unit	42±
17. Silty quartzitic and interbedded calcareous siltstone, dark-gray, iron-stained; generally similar to unit 18 but less indurated. Abundant horn corals, productid and spiriferoid brachiopods and crinoid columnal segments (fossil colln. 58ASa24) along several bedding planes, commonly associated with siliceous nodules like those in unit 18. Some fossils within nodules, which are cut by boxwork veinlets of quartz and limonite. Resistant unit	10
16. Quartzite, dark-gray, silty, brightly iron stained; beds 1–6 ft thick. A few fossils like those in unit 17; scattered siliceous nodules, few spherical limonitic concretions to 6-in. diameter. Massive resistant unit	26
15. Sandstone, very fine to fine-grained, friable to moderately indurated	2
14. Sandstone, dark-gray, very fine grained, quartzitic, slightly calcareous, iron-stained. Contains a few dark-gray chert pebbles	6
13. Conglomeratic and nodular siltstone; about 70 percent pebble-sized round siliceous nodules, argillite, and clay ironstone in matrix of slightly calcareous siltstone. Abrupt contact with unit 12	0.5
Total Echooka Member	152±
Total Sadlerochit Formation (incomplete)	182±

Lisburne Group undivided (incomplete):	Thickness (feet)
12. Limestone, dark-gray, medium to finely crystalline, dense, and light gray, crinoidal, friable to moderately indurated. Tight folds and faults in lower part	50±
11. Limestone, light-gray to medium-gray, highly crinoidal (80 percent of unit); interbedded with darker shaly limestone. Sparse calcite and chert nodules	35±
10. Limestone, gray, mostly shaly (80 percent of unit), micaceous; interlenses with crinoidal limestone. Few scattered chert nodules and iron-stained pyritic concretions less than 1 in. in diameter	10
9. Limestone, gray, argillaceous to silty, soft, laminated. Contains scattered calcite nodules along bedding planes and scattered white-weathering chert lenses parallel to and across bedding in upper part of unit	5
8. Limestone, gray, crinoidal, massive, well indurated to friable	3
7. Limestone, gray, silty, laminated; with thin cherty lenses	0.7
6. Limestone, gray, crinoidal, shaly. Contains distinctive septarian concretions and chert breccia. Concretions are medium-dark-gray, very fine grained limestone that weathers yellowish orange and olive gray; quartz veined	1+
5. Interlensed shaly and crinoidal limestone; chert lenses and chert breccia in upper 3 ft of unit	19
4. Limestone, light-gray, shaly; with lenticular beds of crinoidal limestone as much as 4 ft thick. Grades downward into unit 3	6
3. Limestone, shaly; contains light- to medium-light-gray, yellowish-orange-weathering chert nodules as large as 2 by 6 in., concentrated along several bedding planes. Grades downward into unit 2	8
2. Limestone, medium-gray to medium-dark-gray, highly crinoidal; contains sparse pseudomorphs of limonite after pyrite; friable, massive unit	15
1. Limestone, medium-gray, sublithographic to coarsely crystalline, blocky; beds about 6 in. thick. Interbedded with minor dolomite and medium-dark-gray shaly limestone	Not measured
Total Lisburne Group undivided (incomplete)	153±

Section 10—Shublik Formation, exposed on east wall of Okpilak River valley, 1 mile northeast of Okpilak Lake

[Measured with tape and in part estimated by E. G. Sable and G. R. Kunkle, August 13 and 15, 1957]

	Thickness (feet)
Kingak Shale, siltstone member	Not measured
Shublik Formation:	
Limestone member:	
10. Scattered heavings of grayish-black to dark-gray limestone; black calcareous shale or shaly limestone, soft, sooty, phosphatic; and dark-yellowish-orange, very fine grained to silty, laminated limestone. Sparse fossil fragments of monotid pelecypods, rhynconellid brachiopods, belemnoids(?). Tundra covered	50?
9. Limestone and interbedded limy shale, in alternating sets of beds about 10–30 ft thick. Black, fissile, sooty limestone; silty to sandy calcareous shale containing black phosphatic nodules, about 70 percent of unit. Limestone, dark-gray; weathers grayish black; fine grained, sandy to silty, blocky. Phosphatic nodules average perhaps 15 percent of unit. Phosphate nodules, grayish-black, hard; round to subround to highly irregular in shape, 1/32–2 in. in diameter; some distinctly concretionary, others apparently structureless, noticeably compressed and alined with secondary cleavage. Scattered iron-stained pyritic(?) concretions and nodules as large as 2 by 4 in., spherical to oblong; few scattered clay ironstone nodules. Unit weakly resistant	250?
8. Interbedded limestone types as in unit 9, but blocky sandy limestone about 65 percent of unit and most abundant in lower 20 ft of unit. Blocky limestone beds average ½–1 ft in thickness, as much as 4 ft thick. Black shaly limestone, fissile, in beds less than 1 ft thick, with white efflorescence on surfaces. Phosphate nodules not abundant	63
7. Calcareous sandstone and sandy limestone, dark-gray; weathers dark yellowish brown (10*YR* 4/2); fine-grained; blocky; beds 1–3 ft thick. Contains about 20–30 percent black phosphatic nodules; white efflorescence conspicuous on surfaces of limestone and nodules	20
6. Sandy limestone, dark-gray to black, weathers dark yellowish brown; 60–80 percent phosphatic nodules	2±
5. Sandstone and limestone as in unit 7. About 30 percent phosphatic nodules averaging ½–1 in. in diameter	16
4. Limestone, dark-gray to black, sandy, fine- to medium-grained, blocky to fissile, mostly poorly indurated; white phosphatic efflorescence and nodules. Fossil fragments within 10 ft of top. Phosphate nodules about 5 percent of unit at base to about 15–20 percent near top. Partly covered	200?
3. Sandy limestone and shaly limestone. Sandy limestone, about 70 percent of unit; medium gray, weathers yellowish brown, blocky; ½- to 2-ft-thick beds. Contains about 20 percent black posphatic nodules, ⅛–1½ in. in diameter, with few thin beds composed of about 90 percent nodules. Shaly limestone, black; weathers medium gray to light gray	15
2. Limestone, black; weathers pale yellowish brown; shaly in part. Poorly exposed	50
Total limestone member	666±
Sandstone member:	
1. Sandstone, medium-gray to dark-gray; weathers pale to moderate yellowish brown; fine to medium grained, in part calcareous, blocky; beds 1–1½ ft thick. Contains black phosphatic nodules less than 1 in. in diameter; unit in part has bluish-white efflorescence, resistant	43±
Total Shublik Formation	709±
Sadlerochit Formation, Ivishak Member slate and quartzite.	

Section 11—Thermally altered carbonate rocks, exposed on east-facing mountainside along lower part of Esetuk Glacier

[Measured by E. G. Sable, July 23, 1958; description augmented by thin-section study. Traverse upslope from lowest granite contact]

Interval above granite contact (feet)

Granite:

Granite, coarse-grained; in part tourmalinized or locally light-gray aplitic rock at contact. Foliation in granitic rocks, where present, is generally conformable to contact, but irregular apophyses of granite as much as 10 ft across and 5 ft high invade country rock (fig. 15A). The contact is sharp; granite within 1 ft of contact contains calcite. Hornfels above contact is dark greenish gray, in part banded, contains tremolite-actinolite (40 percent), epidote (30 percent), clinozoisite(?) (20 percent), and quartz (10 percent) 0–6

Thermally altered carbonate rocks:

2. Hornfels, aphanitic, greenish-gray to rose, Hornfels, includes bands of red garnet as much as 1 in. thick. In thin section the bands are about 70 percent grossularite (n=1.765+0.003) in part with anomalous birefringence enclosing crystals of hedenbergite, and fine-grained groundmass composed of quartz, cordierite(?), calcite, and chlorite, with calcite-quartz veinlets. This unit also contains phyllite and gnarled red, green, and gray calcareous rock 6–40
3. Mostly rubble of epidote-amphibolite like that in unit 1 with grossularite concentrated in bands, sphene in chloritic bands, and lesser amounts of green-stained rock containing massive, dull-gray, very fine grained magnetite. Interval estimated 40–80
4. Aphanitic rock, massive, banded, olive-green to dark-green, dense, hard, with gnarled banding and gunmetal-blue stain 80–87
5. Limestone, platy, dark-gray; in part altered; very soft, sandy, laminated. Consists of calcite matrix with grains of subround quartz, chert, and minor plagioclase, dark-gray carbonaceous and white to yellow opaque material 87–98
6. Aphanitic rock, red and green, gunmetal-blue stained; some green and blue bloom (copper carbonates). An epidote-amphibolite showing much cross-shearing indicating two directions and stages of disturbance 98–143
7. Covered 143–163
8. Green chloritic schist 163–168
9. Granite rubble. Granite truncates country rock above this unit, which is hedenbergite-grossularite-quartz-cordierite rock with abundant accessory sphene and pyrite, and shows shearing effects similar to those in unit 6.

NOTE.—Units 1, 3 and 6 are interpreted to belong to the albite-epidote-amphibolite facies, and units 2 and 9 to the hornblende hornfels facies, calcareous assemblage with excess quartz (Fyfe and others, 1958, p. 201–211). Except for unit 1, considered to be anomalous in its position adjacent to one granite contact, the mineral assemblages seem to indicate progressively decreasing metamorphic grade away from the granite.

Section 12—Section across granitic rocks—Kekiktuk Conglomerate contact, exposed on east valley wall of Okpilak River, 3.5 miles south of Okpilak Lake

[Measured with tape and in part estimated by E. G. Sable, August 16, 1957; description augmented by thin-section study]

Interval above granite contact (feet)

1. Granite, fine to very fine grained, iron-stained; overlying coarse-grained microcline-megacryst granite. The fine-grained granite contains quartz, microcline, highly sericitized albite, and dark-brown to bleached, ragged biotite which contains abundant inclusions of magnetite, apatite in relatively large crystals, and euhedral zircon.
2. Rubble of aplitic rock, light-gray, partly iron stained; consisting of alined intergrown mass of quartz, plagioclase, microcline, and sparse biotite 0–20
3. Schistose granite(?), dark-greenish-gray; with relatively fresh to altered microcline megacrysts as much as 2 in. in length, and quartz megacrysts as much as ½ in. in diameter. Thin sections of these rocks show that they are made up mostly of a fine-grained quartz-sericite-chlorite groundmass, in part showing a metamorphic flow texture around the quartz megacrysts. Microcline in different thin sections ranges from partially to completely sericitized, with some chlorite. Ragged and shredded remnants composed of chlorite and (or) muscovite containing abundant magnetite, apatite, and garnet are interpreted to represent altered biotite 20–40
4. Schist, grayish-green; with quartz megacrysts. Mostly a microaggregate of quartz and sericite; chlorite and muscovite with inclusions, probably after biotite; patches of calcite; and large patches of sericite, probably after microcline 40–45
5. Schistose rock like that in unit 3 but without microcline 45–55
6. Aphanitic schistose rock, medium-dark-gray; in part silicified, with quartz megacrysts. Sericite-chlorite groundmass; chlorite and muscovite shreds and patches after biotite; quartz as megacrysts and apparent grains. Upper part, a quartz-sericite schist; contains quartz megacrysts to 1-in. diameter, with more abundant subround to subangular grains of quartz. Strong metamorphic flow texture of groundmass around grains 55–95
7. Quartzite, medium-dark-gray, schistose, coarse-grained; with some color banding. In thin section much like rocks in unit 6 but with weaker schistosity and flow texture, some patches of chlorite with inclusions like those in biotite of granite, and quartz grains 95–105
8. Covered to Lisburne Group. Interval estimated 105–155

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