GEOLOGY OF THE ROMANZOF MOUNTAINS, BROOKS RANGE, NORTHEASTERN ALASKA

by
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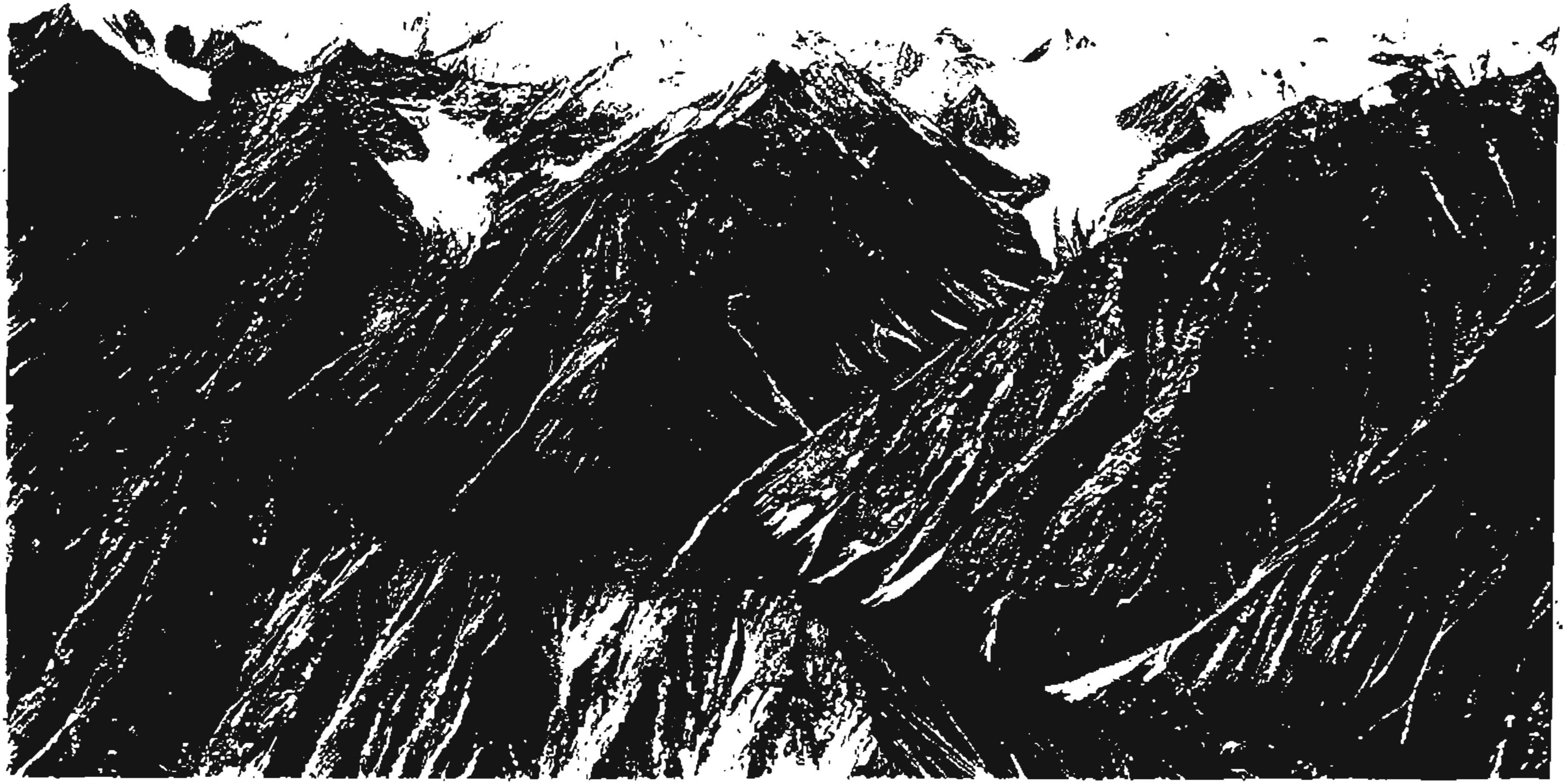

FRONTISPIECE. Oblique view of Romanzof Mountains along Okpilak River valley, looking west. In a spectacular scenic area, mountains composed of Romanzof granite rise to altitudes of 9000 feet. Features of Pleistocene and Recent glaciation abound. Photo by U. S. Navy.

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In the Romanzof Mountains, a small granite batholith has intruded a thick sequence of pre-Mississippian metasedimentary rocks. Younger sedimentary units ranging from Mississippian to Cretaceous in age adjoin the batholith on the north. Intense deformation has resulted from Late Devonian and Cretaceous orogenies.

Rocks of sedimentary origin include:

1. Neruokpuk Formation (Middle and Upper Devonian (?)), more than 4000 feet thick, consisting of low-grade metamorphic equivalents of graywacke, pelitic, and carbonate rocks.
2. Kekiktuk Conglomerate and Kayak(?) Shale (Upper Devonian(?) and Mississippian), as much as 400 feet thick. An angular unconformity at the base may reflect either a pre-Kayak(?) or pre-Kekiktuk hiatus or both.
3. Lisburne Group, predominantly carbonate rocks, 600 to 800 feet thick. Alapah Limestone (Upper Mississippian) includes dark cherty carbonate rocks in the upper part. The lower contact is gradational. Wahoo(?) Limestone (Pennsylvanian(?) and Permian) is characterized by crinoidal limestone.
4. Sadlerochit Formation, consisting of three units: ferruginous sandstone member (Lower(?) Permian), about 200 feet thick, which unconformably overlies the Lisburne Group; shale member, averaging 400 feet thick; and quartzite member (Lower Triassic), 700 feet thick. Basal clastic components were probably shed from a northern source area.
5. Shublik Formation (Middle and Upper Triassic), 600 to 700 feet thick. The sandstone member is overlain by dark phosphatic limestone and shale.
6. Kingak Formation (Jurassic), more than 1000 feet thick. The relatively thin siltstone member is overlain by black shale. A disconformity at the base of the formation is suggested.
7. Ignek(?) Formation (Cretaceous), containing lithic graywacke, shale, and coaly shale.
8. Glacial and glaciofluvial materials which indicate five advances (Pleistocene and Recent).

The Romanzof granite, exposed in the Okpilak batholith and Jago stock, is mostly light-gray quartz monzonite to granite with perthitic microcline, albite-oligoclase, and partly chloritized biotite. Gneissic, gneissoid and schistose textures are common. Limited modal and chemical data are presented. Three textural facies are recognized: porphyritic (marginal), variable (middle to marginal), and coarse (inner to marginal). Aplite, quartz-monzonite, and mafic dikes, as well as tourmaline, chlorite, and quartz veins are locally common. Granite-country rock contacts are either abruptly concordant to cross-cutting, with locally adjoining tactite and hornfels, or gradational into schistose rocks. Most primary and secondary structural elements in granitic rocks are steeply dipping. Lead-alpha ages of zircons are Paleozoic; K-Ar ages of biotite are Cretaceous. Field relationships suggest pre-Kayak(?) (Upper Devonian) granite emplacement with later superimposed orogenic effects. The pluton is interpreted to be the product of melt crystallization, synorogenically emplaced by forceful injection with minor stoping, and may include marginally granitized rock. Mafic (greenstone) dikes and volcanics(?) are interpreted to be of Late Devonian age.

Structural elements include the major positive nature of the area (first order), relatively broad folds (second order), and small tight folds (third order). Cleavage, schistosity, and some biotite foliation in granite are related to third order folds, and are cut by steeply-dipping transverse joints and faults. Other features include longitudinal normal and reverse faults, overthrust faults, and shear zones in granite. Some Mesozoic structural features were probably controlled by pre-existing Paleozoic features.

Although Mesozoic and Tertiary deformational features are dominant in northern Alaska, the Romanzof area may have been part of a Late Devonian orogenic belt continuous with one in northern Canada. Evidence for three alternate trends of such a belt in northern Alaska includes distribution of known Late Devonian clastic rocks, distribution of granitic plutons, and results of gravity studies.

No mineral deposits of econimic significance were found in the area. Zones and areas of disseminated pyrite are widely scattered; chalcopyrite and galena occur locally in small veins; and molybdenite is locally disseminated in the granitic rocks. Rock phosphate is present in the Shublik Formation.

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INTRODUCTION

The Romanzof Mountains represent an area that is geologically unique in northern Alaska; they not only contain the one known granitic pluton on the northern side of the Brooks Range, but also have more geological variety than any area of comparable size in this region. The diversity of geologic phenomena is reflected in the presence of well-exposed granitic masses with a variety of contact relationships, regionally metamorphosed clastic and carbonate rocks as well as realtively unaltered sedimentary rocks, mafic intrusives and volcanics(?), and minor metallic mineralization. The age of bedrock units ranges from at least Middle Devonian(?) to Cretaceous with possibly all intervening geologic systems represented. Evidence of at least two probable major unconformities are recorded in the bedrock geology, and other unconformities may be present. Pleistocene and Recent times are represent by striking examples of piedmont and valley glaciation effects. Structural 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. If the area were situated in a less remote part of the world, it would probably be considered a classic geological field laboratory.

Location, Size, and Accessibility of Area

The Romanzof Mountains lie within the Mount Michelson and Demarcation Point Quadrangles, Alaska, and cover about 700 square miles. They are approximately bounded on the east and west by the Jago and Hulahula Rivers, and lie between latitudes 69°05' and 69°27' N. (fig. 1).

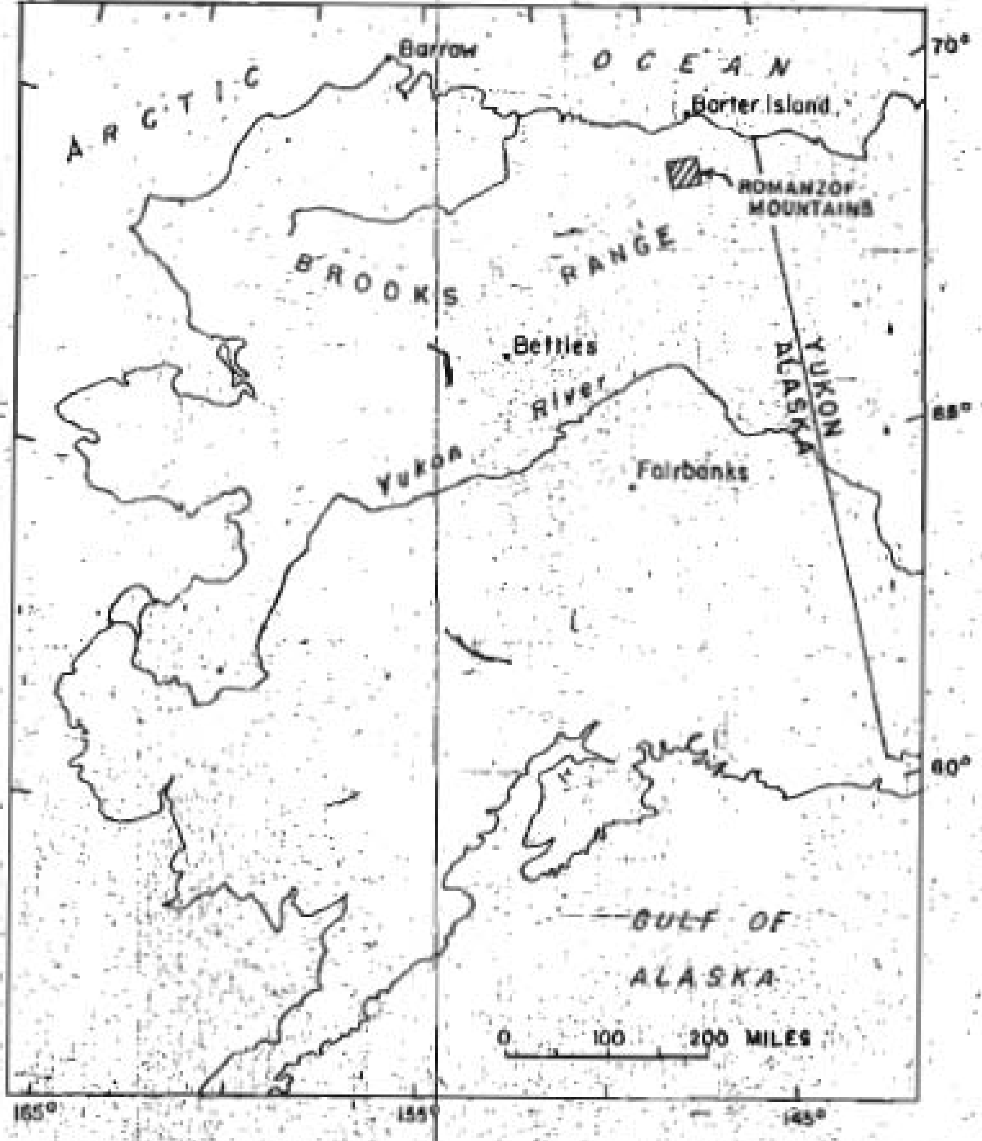

Figure 1. Index map of Alaska, showing location of Romanzof Mountains.

Airline distances to the nearest 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, and access is most easily accomplished by use of small float- or ski-equipped aircraft. Within the area, travel is best accomplished on foot; tracked vehicle travel would be extremely difficult or impossible south of the mountain front. Shallow draft boats might be used on the major rivers, particularly on the Hulahula, the largest and deepest stream in the area.

Previous Investigations

The Romanzof Mountains were first 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 portion of the mountains between the Hulahula and Jago Rivers by Ernest de K. Leffingwell (1919, p. 50), who, while single-handedly undertaking geologic and topographic investigations in northeastern Alaska, made two trips into the area. Geology accomplished on these trips was of a reconnaissance nature, and served to outline some of the major rock units and gross structural character of the Romanzofs. Leffingwell was an acute observer; many of his conclusions have been verified by later work, 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 along the Okpilak and

Hulahula Rivers and along the front of the mountains between these rivers (Whittington and Sable, 1948, 1960). This work resulted in relatively few refinements on Leffingwell's earlier observations.

Nature and Scope of Present Investigation

Field studies undertaken during the summers of 1957 and 1958 were parts of a project planned by the author in 1956. The purpose of the overall project is to produce a relatively detailed geologic map of the area, to determine the age and relationships of the various rock units, to compare the sedimentary and metamorphic rock sequences with those in other areas of northeastern Alaska, and to evaluate the structural features and possible economic mineral potential. Understanding of the tectonic significance of the area in relation to the overall framework of the Brooks Range was perhaps the most important conclusion hoped to be gained from the studies.

The present report is descriptive and interpretative. Because it covers a wide variety of geologic features, it is difficult to ascribe its contents to concentration in any one subject. Most of the writer's efforts, however, were devoted to studies of structure, physical stratigraphy, and the granitic rocks; observations of glacial features were incidental to bedrock studies. The results are considered to be semi-detailed in nature, although the amount of data exceeds that from most Alaskan areas.

Field work was undertaken from June 10 to August 25, 1957 and from June 10 to September 2, 1958. The writer was assisted by George R. Kunkle in 1957 and by Ralph S. Bunnell in 1958. Transportation between the area and Point Barrow, the main base of operations, was by ski- and float-equipped aircraft. Base camps were established at Jago and Okpilak Lakes from which temporary camps were made by backpacking and air-dropping of food and equipment. Professor William C. Kelly, University of Michigan, visited the party in August, 1958 for consultation purposes.

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

The sedimentary rocks exposed in the northwestern part of the area, between the Okpilak and Hulahula Rivers, have been described by Bunnell (1959). Studies of glaciation along the Jago and Okpilak Rivers are reported on by Kunkle (1958). The writer gratefully acknowledges their help in covering this large area in a relatively short time.

Acknowledgments

The field work in 1957 and 1958 was made possible in part by a grant from the Office of Naval Research, U. S. Department of the Navy, as administered through the Arctic Institute of North America. Support by the U. S. Geological Survey, as well as the Arctic Research Laboratory staff at Point Barrow, supervised by Max C. Brewer, is also gratefully acknowledged. In addition, the author wishes to acknowledge the aid given him by 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, Kunkle, and Keeler are incorporated in this report, as well as the work of Whittington and Sable west of the Hulahula River. Bruce L. Reed, U. S. Geological Survey, confirmed identifications of some minerals by x-ray diffraction and petrographic methods. Vera H. Sable assisted in editing the report as well as typing the manuscript.

The writer much appreciated the active interest evinced and consulting aid given by Professor W. C. Kelly during his visit to the area. Thanks is also due to Professor E. N. Goddard, University of Michigan, for his advice during report preparation.

GEOGRAPHY

Topography and Drainage

The highest and most rugged mountain mass in the northern Brooks Range, the Romanzof Mountains reach altitudes of more than 9000 feet, with relief as much as 7000 feet. They are nevertheless a relatively small group of mountains compared to other components of the Brooks Range, the Endicotts, Bairds, and DeLongs. The Romanzofs rise rather abruptly from low hills to the north, and their northern parts consist of high, mostly rubble-covered uplands with terrace-like erosional surfaces at several altitudes, linear ridges, and massive, irregularly-shaped mountains. These rise gradually towards the central part of the Romanzofs where massive, precipitous mountains with jagged peaks and ridges are the dominant topographic features (frontispiece). Many valley glaciers as much as 6 miles long head in the higher parts of the area, and several small ice caps include one that covers the vicinity of Mount Michelson, one of the highest peaks in the Brooks Range.

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

Over-graded and unstable slopes are common in the area and, as a result, numerous examples of soil creep, soil flow, and other evidences of surface material instability are present in the area. Rock falls and small avalanches are a common occurrence in the higher mountains. Patterned-ground features are abundant in the foothills north of the Romanzofs, and the entire area is probably underlain by permafrost. There is little doubt that in these high latitudes and altitudes, mechanical disintegration is currently of prime importance as a weathering agent.

STRATIGRAPHY

Sedimentary and metasedimentary rock units in and adjoining the Romanzof Mountains include more than 8000 feet of mostly marine clastic and carbonate rocks, ranging from probable Devonian to Cretaceous in age. The units and their general character and thicknesses are shown in table 1. Rocks of Devonian(?) age appear to reflect miogeosynclinal depositional environment; younger Paleozoic and Triassic sequences have shelf characteristics; Jurassic and Cretaceous rocks may indicate miogeosynclinal conditions.

Subsequent to the preliminary descriptive reports on sedimentary and metamorphic rocks in part of the area (Sable, 1959; Bunnell, 1959), regional studies in the eastern Brooks Range by the U. S. Geological Survey (Brosge, Dutro, Mangus, and Reiser, 1962) have continued. Because of this work, the preliminary findings and interpretations of Romanzof Mountain stratigraphy have been reexamined and reevaluated, and the current interpretations, which supersede those in the 1959 reports, include: 1) the possibility that the relative stratigraphic positions of some units in the Neruokpuk Formation along the Jago River previously reported (Sable, 1959, p. 19-25) were incorrectly interpreted; 2) the probability that rocks representing the Skajit Limestone of the southern Brooks Range are exposed in the northwestern and possibly eastern parts of the area; 3) the near certainty that the quartzites, conglomerates, and shales ascribed to the Kayak Shale (Sable, 1959, p. 26-35) are

Table 1. Summary of sedimentary rocks and surficial deposits, Romanzof Mountains, northeastern Alaska.

AGE	NAME OF UNIT	APPROXIMATE THICKNESS (in feet)	GENERALIZED DESCRIPTION
Pleistocene-Recent	---	0-200?	Glaciofluvial and alluvial silt, sand and gravel; mostly granitic constituents. Ice and ice-contact deposits; till, coarse morainal deposits.
Cretaceous	Ignek Formation	?	Dark-gray shale, sandstone, siltstone, coaly beds.
Jurassic	Kingak Formation	1000+	Predominantly dark-gray clay and silty shale. Basal silty quartzite with minor conglomerate beds.
Upper Triassic	Shublik Formation	600-700	Black phosphatic limestone and limy shale. Basal phosphatic sandstone.
Triassic-Permian	Sadlerochit Formation		
	quartzite member	700±-800?	Medium-gray massive quartzite with interbedded slate, limy sandstone, and minor conglomerate.
	shale member	400± (200-600+?)	Predominantly dark-gray shale and slate, laminated to uniform. Minor thin quartzite beds.
	ferruginous sandstone member	200±	Ferruginous quartzite with minor conglomerate lenses, interbedded with slate and ferruginous sandstone
Permian(?)-Pennsylvanian(?)-	Lisburne Group Wahoo(?) Limestone Alapah Limestone	200?-800 0 -200+ 200?-560	Carbonate rocks. Fine-grained to coarse fossil fragmental limestone, dolomite: lower part silty and

			deposits; till, coarse morainal deposits.
Cretaceous	Ignek Formation	?	Dark-gray shale, sandstone, siltstone, coaly beds.
Jurassic	Kingak Formation	1000+	Predominantly dark-gray clay and silty shale. Basal silty quartzite with minor conglomerate beds.
Upper Triassic	Shublik Formation	600-700	Black phosphatic limestone and limy shale. Basal phosphatic sandstone.
Triassic-Permian	Sadlerochit Formation		
	quartzite member	700±-800?	Medium-gray massive quartzite with interbedded slate, limy sandstone, and minor conglomerate.
	shale member	400± (200-600+?)	Predominantly dark-gray shale and slate, laminated to uniform. Minor thin quartzite beds.
	ferruginous sandstone member	200±	Ferruginous quartzite with minor conglomerate lenses, interbedded with slate and ferruginous sandstone
Permian(?)-Pennsylvanian(?)-Upper Mississippian	Lisburne Group Wahoo(?) Limestone Alapah Limestone	2007-800 0 -200+ 2007-560	Carbonate rocks. Fine-grained to coarse fossil fragmental limestone, dolomite; lower part silty and sandy limestone, minor shale beds.
Upper(?) Mississippian-Upper Devonian(?)	Kayak(?) Shale and Kekiktuk Conglomerate	07-420	Light- to dark-gray silt- to granule-size quartzite interbedded with variable amounts of carbonaceous shale and slate. Local pebble to boulder conglomerate.
Middle and Upper Devonian(?)	Neruokpuk Formation Several informal units.	4000+	Thick gray and brownish or greenish quartzite and schistose quartzite with interbedded slate and minor siliceous rocks. Limestone and silicified carbonate rocks, light gray to black, crystalline to sandy. Argillite, phyllite, slate.

equivalents of both the Kayak(?) Shale and Kekiktuk Conglomerate; 4) the likelihood that the uppermost beds of the Lisburne Group probably include equivalents of the Wahoo Formation; 5) the probability that the structural grain of the Neruokpuk Formation is at considerable variance in complexity and trends to those of younger sequences.

Terminology and Methods

The descriptive terminology pertaining to sedimentary rocks in this report includes the terms bed, sets of beds, unit, sequence, and section. The terms carry only relative thickness connotations. Bed is used to denote a layer of rock that is separated from the adjoining layers by a difference in lithology, a physical break, or both, similar to Payne's (1942) definition of lamina and stratum. Sets of beds denotes a succession of beds of similar lithologic character, as shale, which lie between rocks of visually different character, as sandstone. Unit is used in a general way for any of the above terms, and in a rock-stratigraphic nomenclatural sense. The term sequence suggests an inferred genetic or time connotation for a succession of units. Section denotes a specifically located stratigraphic interval.

The term clastic is used in a general sense for arenaceous and argillaceous rocks as distinguished from those of dominantly carbonate composition, regardless of the latter's mode of deposition. Descriptions of both clastic and carbonate rock types are based on the Wentworth scale, and the adjective prefixes "clay" and "silty" refer to grain size. The term shale essentially follows the usage of Pettijohn (1957, p. 341), as well as the classification of clastic rocks examined in thin section (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 (American Commission of Stratigraphic Nomenclature, 1961, p. 649-654).

Section thicknesses of sedimentary rocks were obtained by several methods, including 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 relatively large area in a limited time period 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.

Devonian(?) System

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 non-carbonate rocks believed to be pre-Mississippian in age, included units of phyllite and argillite, but did not attempt to subdivide the formation.

Sable (1959, p. 17-76) summarized preliminary results of his 1957-1958 investigations, including generalized descriptions of an apparently normal 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) discusses two members of the Neruokpuk north of the granitic rocks between the Okpilak and Hulahula Rivers.

Recent studies by the U. S. Geological Survey in the eastern Brooks Range are summarized by Brosge and others (1962, p. 2182-2185). The Neruokpuk is tentatively subdivided by them into two members west of the Romanzof Mountains, the quartzite-schist member and the younger phyllite-chert member. East of the Romanzofs, they include two additional units in the Neruokpuk Formation, a limestone member and younger limestone-phyllite member which they interpret to lie between the quartzite-schist and phyllite-chert members. In addition, they interpret the base of the phyllite-chert member to represent a regional unconformity of considerable magnitude, in part with angular discordance east of the Romanzof Mountains.

In this report several thick rock units including carbonate rocks are collectively ascribed to the Neruokpuk Formation. Some of these can be provisionally correlated with members of Brosge and others; the status of other units is uncertain. The Neruokpuk Formation is a nomenclatural unit of diverse lithologies in which the paucity of fossil remains, the character and thicknesses of lithic units which indicate the possibility of rapid and as yet unpredictable facies changes, the unconformities within and above the formation, and structural complexity and metamorphism make this unit one of the most enigmatic in the Brooks Range.

Distribution and Outcrop

Rocks here ascribed to the Neruokpuk Formation are exposed almost continuously around the periphery of the granitic pluton except along its northern limits of exposure, northwest of the pluton along the Hulahula River, and along part of Old Man Creek. A few small infolded remnants of this formation lie within or overlie the granite along its western and southern margins. Within the area, Neruokpuk exposures encompass less than 200 square miles, but much more extensive belts of exposure continue southward for about 15 miles, westward for 40 miles, and eastward for at least 60 miles to beyond the Canadian border (Brosge and others, 1962, p. 2175, 2182).

In the Romanzof Mountains, resistant rock types include 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, although the carbonate rocks along the Hulahula River and Old Man Creek are highly resistant, and weather to bold, pinnacled cliffs. Perhaps the thickest and most continuously exposed sections in the area occur in the north-facing mountainsides along the west side of the Jago River between Boulder and Met Creeks. Those along the Hulahula River and Old Man Creek are also well exposed but represent thinner intervals of the known Neruokpuk.

In many places, rocks of the Neruokpuk Formation are highly deformed, with well-developed cleavage and schistosity which masks original bedding features. Entire mountainsides, particularly those south of the granite in the headwaters of the Okpilak River, appear to dip homoclinally southward when viewed from a distance. Closer examination, however, reveals isoclinal folds and zones of shear which generally 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 include carbonate rocks, in part silty to sandy; quartzites and schistose quartzites; phyllites, argillites, and slates; and minor cherty rocks. The total thickness of the formation is not known, but is believed to be in excess of 4000 feet.

Three separate areas in the Romanzof Mountains display somewhat different sequences which at present cannot be correlated with certainty. The three areas include:

1. Jago River.
2. Esetuk Glacier and southward, in Hulahula drainage.
3. Hulahula River and Old Man Creek in northern part of area.

In addition, clastic rocks south of the granite pluton may represent units which were not recognized in the above areas.

1. Jago River.- Sable (1959, p. 19-24) discusses the Neruokpuk rocks in this part of the area and describes a well-exposed section between Boulder and Met Creeks, west of Jago River. Rock units in this reference section, condensed from the 1959 report with thicknesses partly revised, are shown in table 2.

Below this section calc-silicate rocks reflect alteration by emplacement of adjoining granite. Unit relationships in the section appear to be conformable. Bedding faults, if present, may correspond to mineralized zones in unit 1 or lie at the base of units 3, 6, or 7.

Units in the reference section can be traced westward about 3 miles where they are truncated by granite. East of the Jago River, similar units 2 to 3 miles north are

Table 2. Generalized description of Neruokpúk Formation reference section between Boulder and Met Creeks, Jago River.

Map Unit Symbols (Plate 1)	Unit	Approximate Thickness in Feet
nkq	7. Greenish quartzite and schistose quartzite (up to granule size grains, with chloritic and sericitic schist, slate, and minor limy sandstone)	900+
	6. Brown-weathering gray and olive-gray quartzite (up to granule size, with minor siliceous shale or slate)	700±
nkp	5. Gray, greenish, and reddish argillite and phyllite, siliceous shale or slate, and light to dark gray chert	350±
	4. Dark-gray limestone (in part sandy)	300±
nkb	3. Brown-weathering gray quartzite (up to granule size, with minor calcareous sandstone)	400±
nkl	2. Gray limestone and grayish to greenish phyllite (with quartzite, dark slate, and schist)	700±
	1. Black and gray limestone (with very minor slate, phyllite, siltstone and quartzite; sandy limestone in upper part)	1000+

correlated with the above-tabulated units on the basis of lithic and sequential similarity. Unit 3, the brown-weathering quartzite, appears to be the key unit which ties the two belts of exposures; east of the Jago, this is underlain and overlain by units of similar lithology to that in the reference section. Here, unit 3 is probably more than 800 feet thick and on aerial photographs appears to thicken eastward to a point 12 miles east of the Jago, where it strikes under Mississippian rocks. Westward, unit 3 appears to thin and pinch-out before the sequence is truncated by granite.

Correlations with Neruokpuk Formation units described by Brosge and others (1962, p. 2182-2185), are shown in figure 2. Dark limestones of reference section unit 1 seem almost identical to those in their limestone member. Units 2-4 of the reference section probably represent the limestone-phyllite member, as suggested by the sandy nature of the limestone, orange weathering of some carbonate rocks, minor dark shales, and salt-and-pepper sandstones. Unit 5 seems to correspond with the phyllite-chert member, the base of which is believed to represent a regional angular unconformity of considerable magnitude (Brosge and others, 1962, p. 2182-2183). The uppermost units of the reference section, 6 and 7, represent lithologies of the quartzite-schist member. However, their position in the reference section, overlying unit 5 which is tentatively correlated with the uppermost part of the Neruokpuk, does not correspond with the sequence

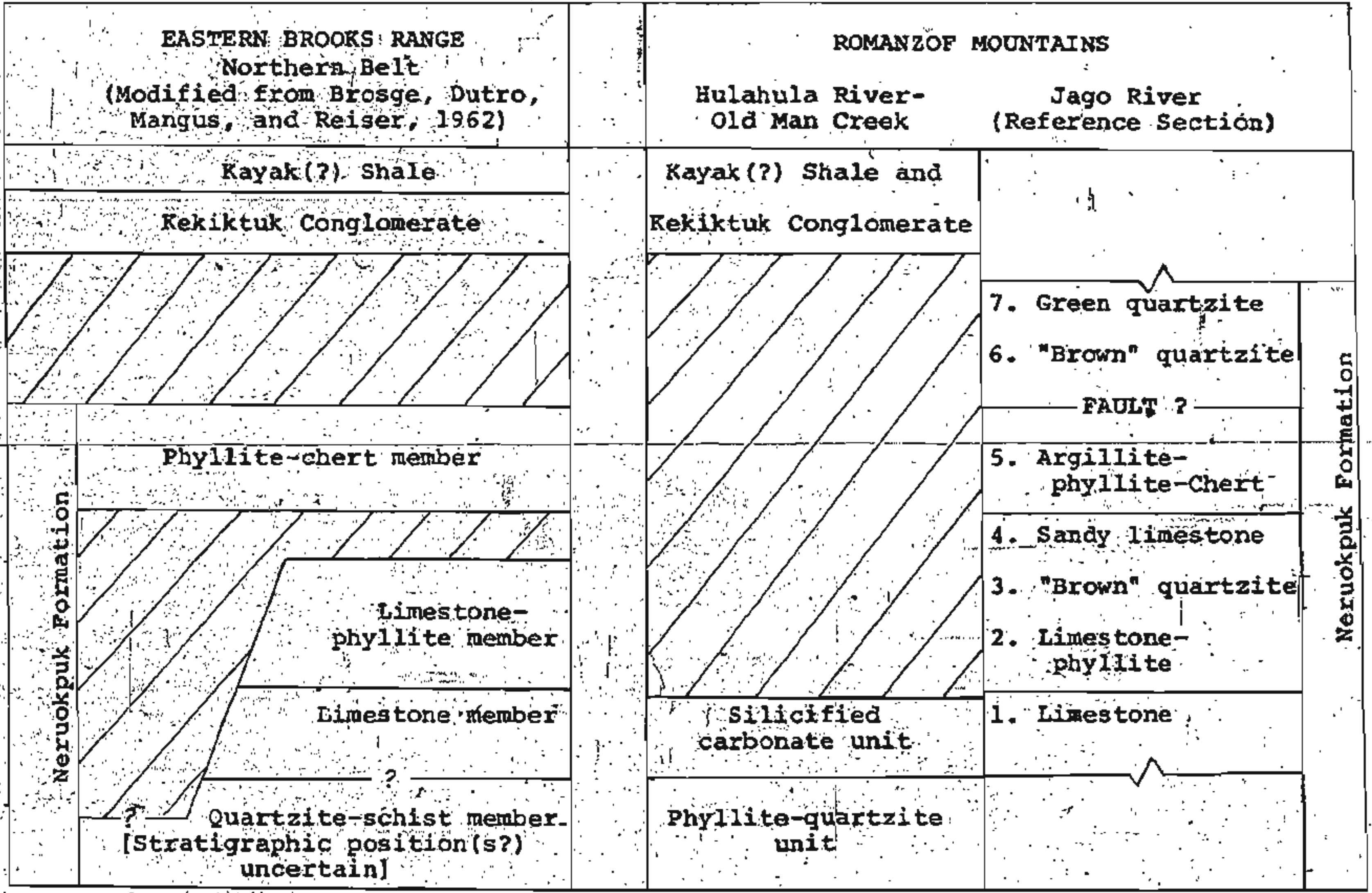

Figure 2. Chart showing suggested correlations of some units of Neruokpuk Formation in Romanzof Mountains with regional units of northeastern Alaska.

described by Brosge and others, who suggest that their quartzite-schist is older than their limestone member. Possible explanations are that quartzite-schist lithologies may occur in more than one stratigraphic interval, or that a major dislocation occurs in the above reference section. If the quartzitic rocks of units 6 and 7 are in reality older than the limestone unit 1, then the quartzites are probably in fault relationship with the underlying unit. The apparent continuity of the sequence on both the west and east sides of the Jago River, however, suggests that it is normal, and the possible presence of a thrust fault within the sequence is not established. If the reference section indicates a normal sequence of rocks, then uppermost units 6 and 7 may represent a mixed assemblage of miogeosynclinal and eugeosynclinal aspect which is equivalent to the thick Upper Devonian Kanayut Conglomerate (Bowsher and Dutro, 1957) in the central Brooks Range and to Upper Devonian clastic sedimentary rocks in the Yukon Territory (Martin, 1959, p. 2420-2422). The possibility that these graywacke rocks may be Mesozoic in age is also worthy of consideration. Both of these possible correlations are speculative.

In thin section the quartzites in the reference section are schistose, and contain about 50 to 90 percent grains which are compressed, sub-round to angular, and poorly sorted and packed. Grains consist of quartz (70 to 95%), plagioclase (probably albite-oligoclase; 5 to 15%), perthitic microcline (5 to 10%), 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 percentage of quartz is higher, the mineralogy resembles that of the granitic rocks of the area. 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 graywackes.

Carbonate rock in the reference section is fine-grained calcite marble with a few floating grains of corroded quartz, chert, and plagioclase. Minor dark opaque material is probably organic; carbonate grains are commonly elongate and sub-parallel.

North of the reference section, rocks which underlie the younger Kekiktuk Conglomerate are poorly exposed on the east and west sides of the Jago River 5 and 5 1/2 miles south of Jago Lake respectively. These consist of perhaps several hundred feet of maroon and greenish phyllite and argillite interbedded with lesser amounts of schistose quartzite. Although no chert was observed in these localities, these rocks may be equivalent to those in unit 5 of the reference section, and appear to resemble rocks ascribed to the youngest beds of the Neruokpuk, the phyllite-chert member of Brosge and others (1962, p. 2184).

Most of the observed Neruokpuk Formation rocks exposed south and west of the reference section are quartzites, schistose quartzites, slates, phyllites, and black graphitic rocks which strike southwest, sub-parallel 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 (Keeler, 1958, personal communication, and aerial and field photograph study by the author) indicates 700(?) feet of quartzitic schist successively overlain by 800 feet of light-gray quartzite, 200 feet of "black slate" infolded with as much as 2000 feet of quartzite and "black slate". The "black slates" appear to lie roughly along strike with dark graphitic rocks exposed farther west in the vicinity of Dark Glacier. Bedrock here was not easily accessible, but morainal material from these rocks included dominant graphitic phyllite, schist, and black limestone, much comminuted sooty-appearing material, and lesser amounts of gray and brownish phyllite and quartzite. "Black slate" is also reported by Keeler (1958, personal communication) to constitute the upper part of the highest mountain in the Brooks Range, 5 miles west of the Okpilak River forks.

Correlation of the graphitic and carbonaceous rocks with the reference section is very tenuous. The most comparable lithologic equivalents, black limestone and slate, occur in units 1 and 2 of the reference section, but the graphitic rocks to the southwest cannot be traced into these units.

Dark graphitic or carbonaceous rocks comprise only minor parts of the exposures examined in the headwaters of the Okpilak River, and are interbedded with or overlie gray and grayish-green chloritic quartzites or quartz-mica and quartz-chlorite schists. The quartzites, with minor interbedded slate, phyllite, and thin limy sandstones, are the dominant lithology in the Okpilak headwaters and are tentatively correlated with units 6 and 7 of the reference section. Their thickness may be in excess of 2000 feet; they overlie about 500 feet of phyllite and quartzite near the forks of the Okpilak and locally are intruded by granite.

2. Esetuk Glacier.- Three lithologic units in the western part of the area include: 1. phyllite-quartzite unit, 2. sandy limestone unit, 3. silicified carbonate unit.

The phyllite-quartzite unit, exposed along the west margins of the granite south of Esetuk Glacier and adjoining the glacier terminus on the east side, is composed mostly of gray to greenish, commonly laminated phyllite, argillite, and slate, with lesser amounts of interbedded greenish to black banded to uniform quartzite. Some rocks are graphitic. The thickness is unknown; as much as 1000 feet may be present.

The sandy limestone unit is exposed mostly as rubble in a northeast-striking band adjoining Esetuk Glacier. Rocks consist mostly of gray sandy and silty limestone, in part banded, which weathers to yellowish brown platy fragments. One thin-section of this limestone contains 80 percent calcite matrix with irregular grains of quartz (17%), chert (1%), and plagioclase (2%). Some crystalline orange-weathering blocky limestone, and black (phosphatic?) shaly to silty limestone are present in what is believed to be the lower part of the unit. The minimum thickness of this unit is estimated as 500 feet.

The silicified carbonate unit, exposed north of Esetuk Glacier terminus, closely resembles the silicified carbonate unit 3 to 6 miles north along the Hulahula River and Old Man Creek (p. 25). Carbonate rocks are generally dark gray and very fine grained to silty, in part laminated, massive to platy, and resistant. No estimate of thickness was made in this area because of structural complexity.

Interrelationships of the three above units are uncertain because of complex structure. Gross relationships of the units where examined, however, and the extension of field data southwestward by photogeologic studies, indicates that the sandy limestone unit lies between Mississippian rocks and the phyllite-quartzite unit. The silicified carbonate unit appears to be truncated by overlying rocks of the phyllite-quartzite unit north of Esetuk Glacier; the truncation may be structural.

Correlations with units in the reference section on the Jago River are very uncertain. The sandy limestone unit may represent sandy limestones in the upper part of unit 1 or in unit 4 of the reference section; parts of the silicified carbonate unit resemble the lower part of unit 1. Phyllite-quartzite unit equivalents may not be present in the reference section; it more closely resembles the phyllites and quartzites locally adjoining the granite near the Okpilak River forks, and those north of the granite along Old Man Creek.

3. <u>Hulahula River and Old Man Creek</u>.- Bunnell (1959, p. 10-24) describes two rock units that he placed in the Neruokpuk Formation; a quartzite member (phyllite-quartzite unit of this report) more than 300 feet thick, and an overlying silicified limestone member (silicified carbonate unit of this report) about 400 feet thick along Old Man Creek, and perhaps 800-1000 feet along the Hulahula River. The silicified carbonate unit was mistakenly included in the Mississippian Lisburne Limestone by Whittington and Sable (1948, p. 6-7).

The phyllite-quartzite unit is exposed in a small area along Old Man 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. Bunnell's quartzite member is here correlated with the phyllite-quartzite unit of the Esetuk Glacier vicinity, and is mapped as that unit on plate 1.

Rocks of the silicified carbonate unit are well exposed on steep mountain sides along Old Man Creek and the Hulahula River. Several partial sections illustrating the variable character of the unit and its unconformable relationships with overlying rocks are shown in figure 3. The lower one-quarter to one-half of the sequence is

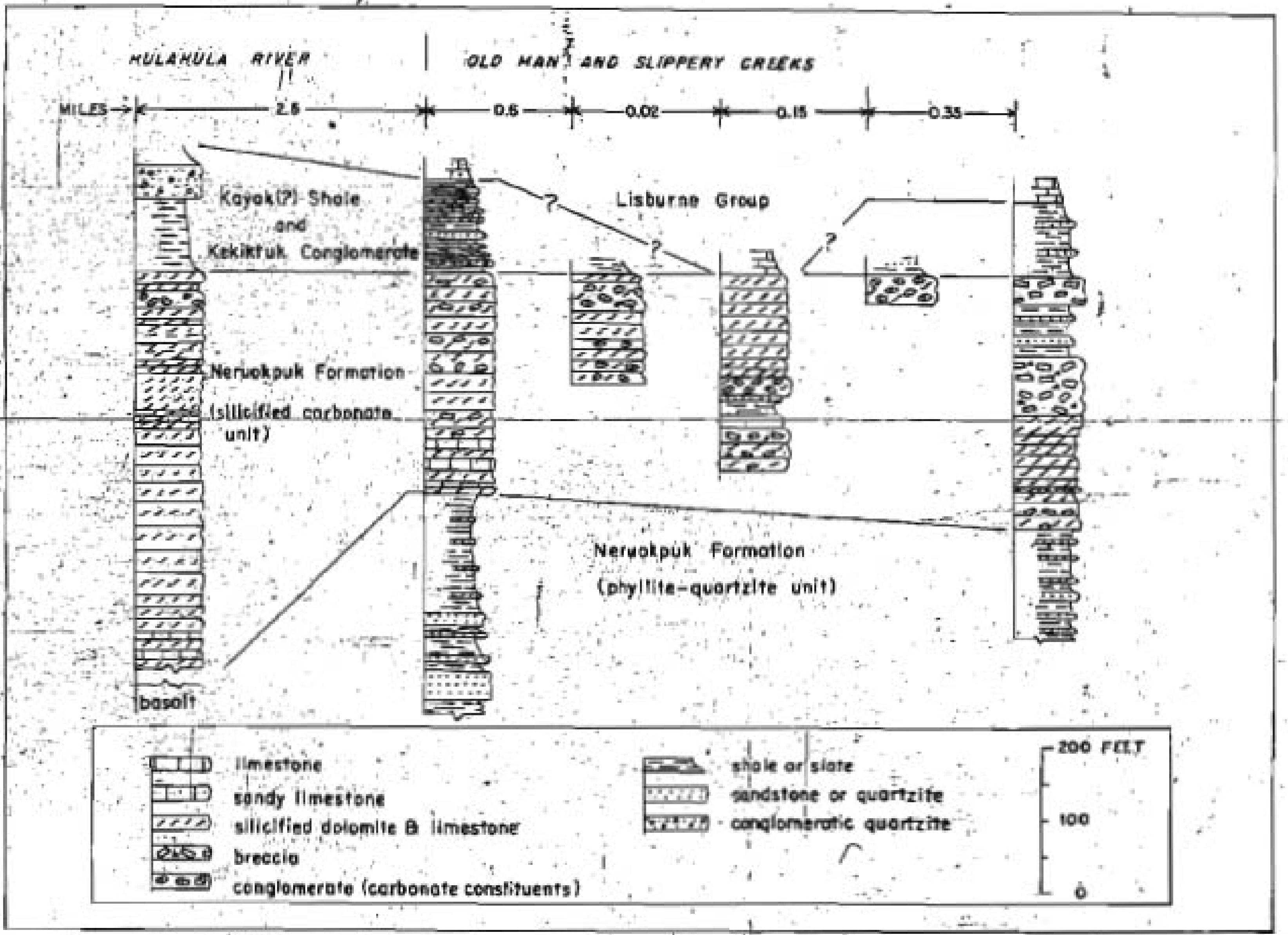

Figure 3. Columnar sections showing relationships of Kekiktuk Conglomerate-Kayak(?) Shale units to Neruokpuk Formation in northwestern part of Romanzof Mountains, Alaska.

dominantly medium- to dark-gray, very fine- to fine-grained, laminated to uniform carbonate which weathers to lighter grayish, yellowish ("cream-colored"), and orange hues, generally in massive, rough-surfaced outcrops. Minor limestone breccia occurs in the lower part, but the upper 150 to 250 feet is characterized by more exotic rock types, such as limestone breccia in units as much as 80 feet thick, granule- to boulder-sized limestone conglomerate as much as 40 feet thick, lesser amounts of interbedded black shale, siltstone and sandstone, and pisolitic to oolitic carbonate. Laminated and uniform limestone beds occur as discrete units and within some of the brecciated units.

In outcrop, limestone breccia occurs in irregular beds and includes mostly tabular limestone fragments commonly less than a few inches in dimensions, but as much as 4 inches by 2 feet. Most fragments, commonly angular, but also subround to round, consist of laminated limestone derived from underlying beds. The matrix consists of very fine grained, in part silicified carbonate and makes up 20 to 60 percent of the rock.

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 matrix.

Non-carbonate clastic rocks, particularly black shale, generally resemble those of the Kayak(?) Shale, but occur as sets of beds between carbonate units. They occur mostly in the upper 50 to 100 feet of the unit, but may occur as low as 150 to 200 feet below the top.

Moderately well sorted pisolitic and oolitic carbonates 10 to 20 feet thick where seen along Old Man Creek, appear to be confined to one horizon in the middle of the unit. Although they form a minor part of the unit, they are present along the Hulahula River (Whittington and Sable, 1960, p. 11), and may prove to be a traceable "key" horizon in future detailed studies.

Most of the carbonate rocks effervesce only slightly with dilute HCl. In thin section, they consist of very fine- to fine-grained intergrowths of 25 to 80 percent anhedral carbonate grains (mostly dolomite) with granoblastic texture, and microcrystalline quartz and carbonate. Rounded carbonate grains in quartz matrix are also present, and ooliths are also composed of intergrown carbonate and quartz.

In many outcrops, rocks of the silicified carbonate unit 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 unit apparently interfingers with and is in part engulfed in volcanic(?) mafic rocks (Whittington and Sable, 1960, p. 12). Its only recognized depositional base in the area is along Old Man Creek. The total thickness of about 350 to 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 1000 feet.

The silicified carbonate unit is overlain by the Kekiktuk Conglomerate, Kayak(?) Shale, and at some localities possibly by Lisburne Group rocks. The precise delineation of this contact, interpreted to represent a major unconformity, is difficult in places because dark shales and siltstones are associated with rocks both above and below the boundary.

Correlation of the silicified carbonate unit with the reference section on the Jago River is uncertain. The lower part of unit 1 in the reference section contains similar laminated dark limestones in which the degree of silicification is not as great as in those described above, but which may be approximately equivalent. Lithologies of the silicified carbonate unit appear to be similar to those in the Skajit Limestone of the Chandalar area on the south side of the Brooks Range (Brosge and others, 1962, p. 2178-2180).

Age

The only identifiable fossil remains found in rocks of the Neruokpuk Formation were scattered crinoid columnal fragments in the silicified carbonate unit. Questionable fossils in the limestones of the lower part of the reference section on the Jago River, and in the silicified carbonate unit consist of small, deformed, calcite- or quartz-filled ellipsoids.

Payne and others (1951) considered the Neruokpuk Formation, as defined by Leffingwell, to be of possible Precambrian age. Brosge and others report no fossils from the Neruokpuk, but tentatively correlate 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. They consider the Skajit Limestone, with which some of the Neruokpuk carbonate rocks may be correlative, to be of Middle(?) and Late Devonian age.

Mississippian and Devonian(?) Systems

Kekiktuk Conglomerate and Kayak(?) Shale

Names and Definition

The Kekiktuk Conglomerate was defined by Brosge and others (1962, p. 2185) 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. They note that similar rocks of this position 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 directly overlies both the Kekiktuk Conglomerate and the Neruokpuk Formation. This was termed Kayak(?) Shale by Brosge and others (1962, p. 2185) because its physical continuity with the type Kayak has not been established.

In this report, dark shale, slate, and minor limestone directly underlying the Lisburne Group are considered to be Kayak(?) Shale equivalents, 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 ascribed to the Kayak Shale in previous reports on this area (Sable, 1959, p. 26-35; Bunnell, 1959, p. 24-30).

Distribution and Outcrop

Widely distributed but sporadically exposed around the eastern, northern, and western peripheries of the Romanzof Mountains, the Kekiktuk Conglomerate and Kayak(?) Shale outcrop in narrow bands adjoining the belts of younger Lisburne Group rocks. Where well developed, they form a distinctive marker unit between Lisburne and older rocks in their lithologic character, type of weathering, and topographic expression. Rocks ascribed to the Kekiktuk Conglomerate are dominant east of the Okpilak River and in local areas along Old Man Creek drainage, where they form cliffs and areas of angular rubble blocks. 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 darker hue where they separate carbonate units.

Character and Thickness

The Kekiktuk Conglomerate and Kayak(?) Shale consist mostly of epiclastic rock types ranging from boulder conglomerates to clay shale. Descriptions of sections along the Okpilak River (Sable, 1959, p. 29-32) and Old Man Creek (Bunnell, 1959, p. 27-29) 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 range from very light- to dark-gray, are commonly medium- to coarse-grained, weather yellowish gray to medium gray, are generally well sorted with respect to size, and are nearly monomineralic, consisting of well packed, subround to subangular quartz grains with a few heavy resistate and chert grains. The matrix, 10 to 30 percent of these rocks, is mostly quartz and calcite, and carbonaceous material is present in the darker varieties. Blocky to massive beds average about 4 feet and are as much as 15 feet thick, and resistant sets of beds are as much as 80 feet thick. The rock is evenly bedded, uniform to banded, and cross-bedding is rare or absent. Few sharp contacts were observed between beds.

Very fine-grained sandstone and siltstone are relatively rare, but occur as transitional units between sandstone and shale. Silty and clay shale is medium gray to black, commonly carbonaceous, and occurs in sets of beds averaging 1 to 2 feet, but as much as 15 feet thick. Macerated coaly plant fragments are locally abundant. Some shale grades to argillaceous sandstone in which medium- to coarse-grained quartz is poorly packed.

Bunnell (1959, p. 24-29) describes the Kayak Shale (Kekiktuk-Kayak(?) unit of this report) in the area of Old Man Creek. There it consists of quartzite, shale or slate and argillite, pebble- to boulder-sized conglomerate in the lower part, and shale with interbedded sandy to shaly limestone in the uppermost beds (Kayak(?) Shale of this report). Lenses of coarse conglomerate, as much as 20 feet thick, are well developed along the major west-flowing tributary of Old Man Creek. Conglomerate constituents are round to subangular poorly sorted fragments of quartzite, schistose quartzite, quartz, phyllite and slate probably derived from the Neruokpuk Formation, and are enclosed in shale and sandstone. At one locality along this tributary, the basal 15 feet of the unit is carbonaceous shale in which 1- to 2-foot thick "lenses" of limestone similar to limestones in the underlying silicified carbonate unit of the Neruokpuk are interbedded. These are interpreted to be blocks of the older unit incorporated in Kekiktuk-Kayak(?) rocks, but may represent upper beds of the Neruokpuk Formation.

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

The Kokiktuk-Kayak(?) unit is highly variable in thickness, ranging from perhaps 0 to about 400 feet; the higher thickness values are mostly due to the presence of the coarser grained rocks. The unit may be locally absent in that carbonate rocks mapped as Lisburne Group appear to rest on pre-Mississippian units. However, bedrock contacts of Lisburne Group with Neruokpuk Formation were not seen during field studies, and rubble-covered intervals of as little as 10 feet between Lisburne rocks and the underlying Neruokpuk Formation or granite may conceal a thin Kayak(?) Shale unit. Apparent thicknesses of Kekiktuk-Kayak(?) along the Jago River range from 40 to 200 feet, but here the unit rests on schistose metasediments and sheared granite; the apparent thickness variations therefore may be misleading because metamorphism has obscured the relationships. Between the Jago River and 3 miles west of the Okpilak River, highly schistose rocks thought to be metamorphosed Kekiktuk and Kayak(?) equivalents adjoin the north front of the granite body, and appear to range from a few feet to more than 100 feet in thickness. In the vicinity of Old Man Creek and the Hulahula River, sections are as much as 120 feet thick, average about 50 feet, but locally the unit is extremely thin or may be absent.

Stratigraphic Relationships and Depositional Character

The Kekiktuk Conglomerate and Kayak(?) Shale overlie metasedimentary rocks of the Neruokpuk Formation 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, 12 1/2 miles south of Jago Lake (plate 1). Bedrock contacts at the base of the Kekiktuk-Kayak(?) were not seen east of the Okpilak River, except where the unit overlies granitic rocks. Here the contact is gradational (p. 142). Throughout the general area, however, the unit rests on several different units of older metasediments, and aerial photograph studies east of the area (Brosge and others, 1962, p. 2183-2184) show distinct angular relationships between Kekiktuk-Kayak(?) and Neruokpuk units.

A disconformity may be present between the Kekiktuk and overlying Kayak(?), both of which rest on Neruokpuk Formation. A clear separation of the two, however, is difficult, although 10 to 50(?) feet of dark Kayak(?) rocks intervene between Lisburne and Kekiktuk rocks at all localities where the three are exposed. Similar shales are interbedded with and locally are basal beds of conglomeratic and quartzitic rocks ascribed to the Kekiktuk. In some 50 to 100 foot-thick sections along Hulahula River and Old Man Creek drainages, Kekiktuk lithologies are absent or very poorly developed, the result of non-deposition, erosion, or facies change. Sections 1 to 4 miles away and 120 feet thick, however, consist of dominantly Kekiktuk type quartzites and conglomerates. An interfingering of Kekiktuk and Kayak(?) lithologies is therefore implied. The Kayak(?) Shale as a thin uppermost unit may then be continuous throughout the mapped area, but in the Romanzof Mountains it is not an easily recognizable interval.

The clastic rocks of the Kekiktuk Conglomerate, including shale with abundant carbonaceous material and coarser clastics which, except for the coarsest conglomerates, are relatively clean and well sorted, are interpreted to represent non-marine or marginal marine deposits, of possible strand-line, swamp, and lagoonal nature. The monomineralic nature of the sand-size deposits may indicate that considerable reworking took place prior to deposition. Crossbedding or other evidences of current or wave action were not observed, and the planar beds imply sheet-like spreading of sand by weak currents unaffected by local climatic disturbances. The pebble- to boulder-conglomerates in the northwest part of the area may be products of torrential streams which debouched into swampy or lagoonal environments. Deposits of the Kekiktuk indicate the beginning of shelf deposition which persisted through at least the remainder of Paleozoic time.

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

Correlation and Age

Correlation of the arenaceous and conglomeratic rocks of this unit in the Romanzof Mountains with the type Kekiktuk Conglomerate is based on similarities in lithology and stratigraphic position. Likewise, the uppermost part of the unit in most sections bears close resemblances to the Kayak(?) Shale in the vicinity of Lake Peters. In the Romanzofs, 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-Kayak(?) unit. If subdivision of the unit is made on a lithologic basis, most of the rocks west of the Okpilak River should properly be referred to the Kayak(?), and those east of the Okpilak to the Kekiktuk. The possibility of a disconformity between the two formations, however, implies that the two may represent discrete time units.

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 Formation or the Noatak Formation, a name now restricted to rocks farther west than any of the above areas (Bowsher and Dutro, 1957, p. 3). Brosge and others (1962) include several Kayak, Kayak(?), and Kekiktuk sections and also depict regional character and thickness of the Kanayut Conglomerate, a unit of Late Devonian age as much as 5000 feet thick which underlies the Kayak Shale in the central and east-central Brooks Range. The Kekiktuk Conglomerate may be an equivalent of the Kanayut, although the base of the latter is not known to represent an unconformity.

The locally abundant plant fragments, mostly in the lower part of the Kekiktuk-Kayak(?) unit, are poorly preserved and indeterminate. The type Kayak Shale contains marine invertebrates of Early Mississippian age. An Upper Mississippian lithostrotionoid coral is reported in the upper part of the Kayak(?) near Lake Peters (Brosge and others, 1962, p. 2186). In the Romanzof area, the Kayak(?) grades upward into the Lisburne Group Alapah Limestone of probable Late Mississippian age. It would therefore appear that, if the Kayak and Kayak(?) represent a continuous sedimentation unit ranging from Early to Late Mississippian in age, it represents deposition along the shores of an eastward or northward transgressing sea.

The Kekiktuk Conglomerate has been assigned a Late(?) Devonian or Mississippian age by Brosge and others on the basis of stratigraphic position. As suggested by them, it may represent a basal Mississippian conglomerate facies, which, with the younger Kayak(?) crosses time lines northeastward. If the Kekiktuk is correlated with the Late Devonian Kanayut Conglomerate, their basal beds may also be inferred to progressively overlap on an Upper Devonian unconformity in the northeast Brooks Range (Brosge and others, 1962, p. 2185).

Rocks along the Alaska-Yukon Boundary reported by Maddren (1912, unpublished notes and partial manuscript) and Mangus (1953, p. 14) appear to be similar in position and lithology to the Kekiktuk, Kayak, and Kayak(?) units farther west, although estimated thicknesses of the eastern exposures are 600 to 1000 feet. Invertebrate fossils from one locality have been tentatively identified as "Kayakian", according to Mangus, who called the entire unit Kayak Formation.

Martin (1959, p. 2421), in discussing rocks of the Yukon Territory and northeastern Alaska, refers the Kayak of Mangus to the Devonian (probably Upper Devonian) and apparently restricts Mississippian rocks to the predominantly carbonate and shaly sequences overlying the coarser clastics. According to this interpretation, Upper Devonian non-marine clastic rocks which are more than 6000 feet thick and indicate a southeastward debouching delta in the southern Richardson Mountains, Yukon Territory (Martin, 1959, p. 2443), are roughly equivalent to the Kekiktuk Conglomerate. Farther west, the thick Kanayut Conglomerate of the central Brooks Range may also be an equivalent unit. 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 to 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, possibly one of orogenic activity during the Late Devonian. This interpretation is discussed later in this report (p. 197).

Mississippian, Pennsylvanian(?), and Permian Systems

Lisburne Group

Alapah Limestone

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 have resulted in this carbonate sequence being raised in rank to the Lisburne Group, including two formations (Bowsher and Dutro, 1957, p. 6). The lower formation, 1230 feet thick, is termed the Wachsmuth Limestone (Lower Mississippian) and consists of banded dolomitic, bioclastic, crinoidal, and shaly limestones, and minor chert. The upper formation is the Alapah Limestone (Upper Mississippian), 970 feet thick; it is subdivided into 9 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.

Brosge and others (1962, p. 2187-2190) have extended the two Lisburne Group formations eastward from their type area, and in the eastern Brooks Range use a member terminology which in part extends members of the type area and is in part new. 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 (Brosge and others, 1962, p. 2190-2192), a carbonate unit of Pennsylvanian(?) and Permian age. The Wahoo also is included in the Lisburne Group (p. 54).

In the Romanzof Mountains, Sable (1959, p. 46) and Bunnell (1959, p. 38) referred to the predominantly limestone sequence between the Kayak(?) Shale and the Sadlerochit Formation as the Lisburne Group. These rocks were considered to be Wachsmuth lithologic equivalents, partly because of the abundance of crinoidal limestone in their upper part, although they contained Alapah fossils. As a result of the published investigations by Brosge and others, it now seems more likely that crinoidal limestones in the upper part of the Lisburne in the Romanzofs represent the Wahoo Formation. In this report the lower part of the Lisburne Group is termed Alapah Limestone and the upper part Wahoo(?) Limestone. Because the Wahoo(?) was not recognized as a separate unit during field studies in the Romanzofs, attempts to delineate it were not made; the two units are mapped together on plate 1.

Distribution and Outcrop

Alapah Limestone rocks are exposed in essentially the same belts as those of Kekiktuk and Kayak(?). East of the Okpilak River, the formation crops out along the north front of the granitic pluton and locally rests on mountains made up principally of the granite. This general 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 Jago. The northernmost exposures east of the Okpilak River are those along Okpirourak Creek.

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, mountain-side exposures covering a large area are common in Old Man and Esetuk Creek drainages and along the Hulahula River valley.

The Lisburne Group 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 make it distinctive and easily recognized, both on the ground and as seen on photographs (fig. 7).

It can be confused only with the silicified carbonate unit of the Neruokpuk Formation (p. 25). whose outcrops, however, are lighter in color and weather to pinnacles and ragged cliffs.

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. The lower half to two-thirds of the Alapah is characterized by arenaceous carbonates and is called the sandy limestone unit; the upper part, mostly dark gray fine-grained carbonates is the dark carbonate unit.

The sandy limestone unit of the Alapah consists of arenaceous and silty to medium-grained crystalline limestone interbedded in some sections with minor amounts of dark-gray shale, quartzite and sandstone, and thin granule to pebble conglomerate in limestone matrix similar to those types in the upper part of the Kayak(?) Shale. Limestone is commonly medium- to medium-dark-gray, blocky to massive, well consolidated to friable, and contains scattered dark- and light-gray chert nodules. Some beds contain abundant crinoidal debris and some sandy limestone is crossbedded. One or more zones of spheroidal sandy chert concretions occur in the upper part of this unit.

The dark carbonate unit of the Alapah contains perhaps 30 to 40 percent dolomite and dolomitic limestone interbedded with limestone. The dolomite is dark- to light-gray, weathers in characteristic grayish-orange and yellowish-orange or dark-gray colors, is very finely saccharoidal to sandy in texture, locally thinly cross-laminated, and occurs in beds commonly less than 1 foot, 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 thinbedded, some units are very thick and massive. The columnar sections (fig. 4) indicate lithologic character of the Alapah, as well as overlying and underlying units.

Thin sections from the Alapah Limestone also indicate silicification similar to that in the silicified carbonate unit of the Neruokpuk Formation, 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. They range from about 560 feet along the Okpilak River, to 410 and 500 feet between the Okpilak and Hulahula Rivers; some sections adjoining granitic rocks

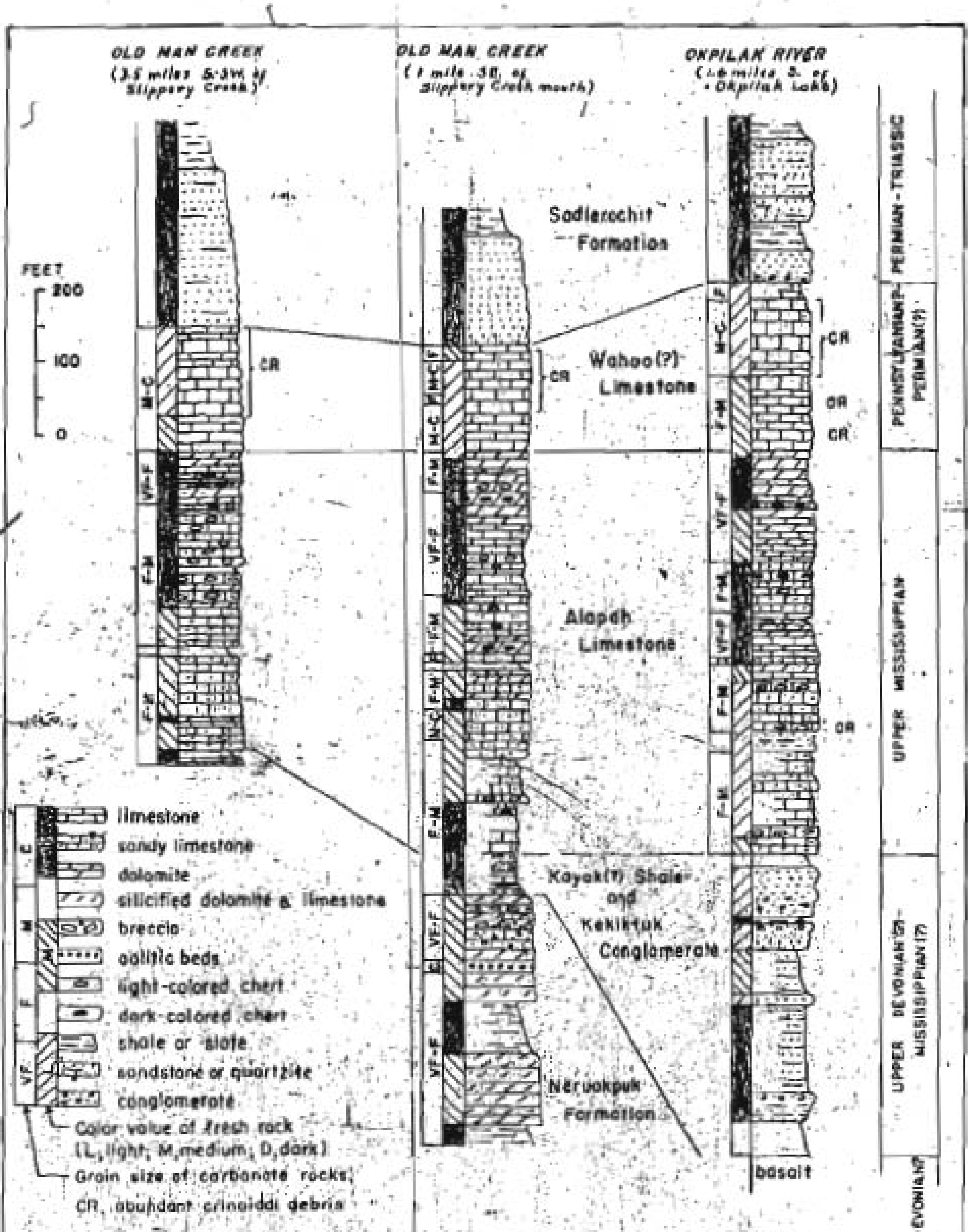

Figure 4. Columnar sections of Lisburne Group and older and younger units in Romanzof Mountains, Alaska.

along Sweat Creek are less than 200 feet thick. Possible reasons for the thickness variations include (1) depositional thickness variations or disconformity within the Alapah, (2) erosion prior to deposition of Wahoo(?) Limestone or Sadlerochit Formation rocks, (3) unrecognized faulting, (4) the equivalence of Kayak(?) Shale in parts of the area to basal Lisburne rocks exposed elsewhere, (5) deposition of Alapah Formation on an irregular terrain, and (6) assimilation or replacement by granite. It is concluded that gross thickness variations within the Alapah not adjoining the granite 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 from about 150 to 300 feet in thickness; the maximum thickness range of the sandy limestone unit in complete sections is 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 appears to maintain a fairly consistent position relative to orange-weathering dolomites in the uppermost part of the Alapah and to a dark cherty zone 40 to 70 feet below the Wahoo(?) (fig. 4). Where the Sadlerochit Formation overlies Alapah rocks (p. 66), 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 along the Jago River are structurally too complex for confident thickness estimation. The southernmost belt east of the Jago, however, covers a broad area, and aerial photograph thickness estimations in this belt 3 to 10 miles east of the Jago River indicate that the Lisburne Group probably exceeds 2000 feet. On the Kongakut River, 50 miles to the east-southeast, the Alapah Limestone is more than 1580 feet and the overlying Wahoo more than 1330 feet thick (Brosge and others, 1962, fig. 5, p. 2187). West of the Romanzof Mountains, the Lisburne Group is at least 600 feet thick and perhaps as much as 1000 feet on the west side of the Hulahula River (Whittington and Sable, 1960, p. 31). Fifteen miles west, Brosge and others report the Alapah to be 1378 feet thick and the Wahoo 447 feet thick near Lake Peters. About 60 miles south, their section on Sheenjek River indicates more than 1360 feet of Alapah Limestone. Northwest of the Romanzofs, a minimum figure for Alapah is 1100 feet in the Sadlerochit Mountains (Whittington and Sable, 1960, p. 31). It therefore appears that, except for the unknown subsurface thicknesses to the north and northeast, the Alapah sequence thins rather abruptly, at least from easterly and westerly directions, towards the Romanzofs.

Stratigraphic Relationships and Depositional Character

Contacts between the Alapah Limestone and Kayak(?) Shale are 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.

No significant stratigraphic breaks were recognized within the Alapah in the Romanzof Mountains. Some irregular bedding contacts and rare intra-formational conglomerates are present, but their significance is not known.

The Alapah underlies the Wahoo(?) Limestone in most of the Romanzof area west of the Jago River with the exception of the belt adjoining the north side of the granite, and a few places in Old Man Creek drainage (Bunnell, 1959, p. 38), where 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 area at a later date than in the central Brooks Range (Sable, 1959, p. 47-48; Brosge and others, 1962, p. 2185). Possibly the Kekiktuk clastic rocks, and at least Kayak(?) argillaceous rocks and Alapah sandy carbonates are interpreted to represent time transgressive units in which successively diminishing amounts of clastic material were shed, possibly from a northern source. The presence of fine crossbedding and sandy character, the relatively abundant faunal remains, and the light colors in the lower Alapah indicate a shallow shelf-type environment with weak to moderate current activity.

The darker generally finer-grained and sparsely fossiliferous dolomitic rocks in the upper Alapah may indicate a deeper and more restricted environment.

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, although 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 come from the sandy limestone unit.

Concerning the corals from the Alapah Limestone of this area, Duncan states:

> "None of the corals from beds assigned to the lower part of the Lisburne Group (author's note- Alapah Limestone of this report) 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 formation."

Table 3. Faunal identifications from the Alapah Limestone, Romanzof Mountains, Alaska.

General Location	USGS No.	Stratigraphic Position	Identification
Old Man Creek	19566-PC	5-10 ft. above base	Fenestella sp. Echinoconchus sp. Spirifer aff. S. tenuicostatus Hall fish tooth, indet.
Jago River	19567-PC	within 10 ft. of base	Lithostrotionoid coral, genus indet. Syringopora cf. S. aff. S. hyperbolotabulata Chi (occurs in Lower Alapah (USNM loc. 3087) in central Brooks Range)
Old Man Creek	19568-PC	10-20 ft. above base	Horn coral, indet.
Old Man Creek	19569-PC	20-30 ft. above base	Horn corals, indet. (fragments suggestive of Faberophyllum complex)
Okpirourak Creek headwaters	19570-PC	approx. 50 ft. above base	Siphonodendron?, sp. indet. (preservation very poor)
Tributary of Hulahula River	19571-PC	lower 50 ft. (?)	Faberophyllum?, sp. indet. Fenestella sp. brachiopod fragment, indet.
Old Man Creek	-	within 100 ft. of base	cephalopod?, indet.
Jago River	19572-PC	within 100 ft. of base	Gigantoproductus, sp. indet. bellerophontacean gastropod, indet.
Tributary of Hulahula River	19573-PC	?	Faberophyllum?, sp.
Jago River	19574-PC	?	Siphonodendron, sp. indet.

Dutro adds:

> "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, the author tentatively identified lithostrotionoid corals which were not collectable from several other places within 100 feet of the base of the Alapah. Lithostrotionoid corals reported within 50 feet of the top of the Lisburne (Sable, 1959, p. 47), now considered to be from the Wahoo(?) Formation of post-Mississippian age, are apparently a new genus of unknown age affinities (p. 57). Tentative 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 part of the Alapah appear to be similar to those in sections of Alapah limestones described by Brosge and others elsewhere in the eastern Brooks Range. The sandy to quartz-granule character of the limestones in the lower part of the sequence, however, does not appear to have identical lithic counterparts in sections shown by Brosge and others, although Mangus (1953, p. 15) reports 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 the Romanzof area itself.

Wahoo(?) Limestone

Name and Definition

Brosge and others (1962, p. 2190-2192) have named the uppermost part of the Lisburne Group in the eastern Brooks Range, the Wahoo Limestone. The Wahoo occurs at almost all eastern Brooks Range localities, and is divided into two members by Brosge. 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 Permian beds of the Sadlerochit Formation in its eastern exposures and the Siksikpuk Formation (Early(?) Permian) farther west. The Wahoo is considered to be probably Pennsylvanian and Permian, and the lower part may represent most of Pennsylvanian time.

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 Alapah limestones and overlying Sadlerochit Formation. The faunal character in collections made from these rocks is apparently not diagnostic, although possibly comparable to collections in established Wahoo Limestone.

Distribution and Outcrop

The Wahoo(?) Limestone is best developed 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 farther south along the Jago River.

Crinoidal limestones in the Wahoo(?) are distinctive in their light-weathering colors relative to the uppermost dark carbonate unit of the Alapah, visible on some aerial photographs. They commonly weather to cliffs and massive ledges, but are locally friable.

Lithologic Character, Thickness and Relationships

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 upwards. Coquinoid beds consisting mostly of bryozoan and brachiopod fragments were seen in a few exposures near the base. Chert and dolomite are conspicuously absent or very minor in occurrence.

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, weather whitish- to light-gray, are well consolidated to friable, and weather 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 more than 200 feet. The crinoidal limestone occurs in sets of beds from 40 to 130 feet thick. Some of the thickness variation of the crinoidal limestone may be the result of intertonguing with the lower part of the formation which appears to range from 35 to 100 feet thick, but most of it is probably 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 Sadlerochit Formation quartzites overlie dark limestones and dolomites interpreted to be upper 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 while those of the basal Wahoo(?) are gray-weathering fossiliferous limestones.

Age, Correlation, and Depositional Character

Three invertebrate fossil collections which can be confidently ascribed to Wahoo(?) Limestone are shown in table 4.

These were identified by J. T. Dutro, Jr. and Helen Duncan of the U. S. Geological Survey.

Table 4. Faunal Identifications from the Wahoo(?) Limestone, Romanzof Mountains, Alaska.

General Location	USGS No.	Strati-graphic Position	Identification
Okpilak River	19577-PC	Less than 100 ft. below top	Fenestella, 2 spp., indet. Fenestrate bryozoan, indet. (apparently a genus with a coarse superstructure cf. Isotrypa)
Old Man Creek	19176-PC	Probably lower or basal part	Davidsonina? sp. Neospirifer? sp. pectenoid pelecypod fragment, indet.
Old Man Creek	19175-PC	20 ft. below top	echinodermal debris, indet. colonial coral, cerioid dibunophyllid, probable new genus "Dictyoclostus" sp. Neospirifer? sp.

In addition, Duncan remarks:

"Few corals were obtained from the upper part of the Lisburne section (author's note- Wahoo(?) of this report). Those that do occur are types found in the later part of the Lower Carboniferous." [author's note- 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 Duncan as being questionably in the upper part of the sequence, is almost certainly Alapah.]

Dutro adds:

"The spiriferoid brachiopods suggest a correlation with higher parts of the Alapah Limestone or the Wahoo Limestone, although nothing diagnostic occurs in these collections."

Rocks of the Wahoo(?) Limestone in the Romanzof area in general resemble those described in the Wahoo by Brosge and others (1962, p. 2191), particularly the coarse-grained crinoidal limestones of their upper member. Rocks like those in Brosge's lower member were not recognized with certainty in the Romanzof area. Near Lake Peters, 15 miles west of this area, the lower member is 447 feet thick and is overlain by the Sadlerochit Formation. In the Romanzof area, it is uncertain whether the lower member is absent, present only in the lower 35 to 100 feet, or is represented by a dominantly crinoidal facies. Further work between Lake Peters and the Romanzofs is necessary to determine the equivalency of the rock units.

Like the Alapah Limestone, Wahoo(?) Limestone is thinner in the Romanzof area than in Wahoo sections measured within 75 miles southeast and southwest and appears to lie along the northern margin of an easterly trending depositional basin (Brosge and others, 1962, fig. 5d, p. 2187). In the Yukon Territory, Martin's observations (1959, p. 2425-2426, and fig. 7, p. 2423, and fig. 20, p. 2448) indicate more than 3000 feet of Permo-Pennsylvanian rocks. These include Pennsylvanian limestones perhaps as much as 2800 feet thick and Pennsylvanian-Permian marine clastics and minor limestones (in part Sadlerochit Formation equivalents?) perhaps 1000 to 1500 feet thick. Relationships of the carbonates and clastics is not known, but the thick carbonates occur along a projected trend of the easterly-trending Wahoo carbonate depositional basin shown by Brosge and others. The carbonate and clastic depositional basin shown by Martin trends northeasterly. A large-scale regional picture indicates an elongate mildly negative area during Middle Pennsylvanian to Lower Permian time which strikes northeastward toward the Canadian Arctic Islands (Martin, 1961, p. 448).

In the Romanzofs, lighter colors, bioclastic nature, and more massive character of the lower part of the Wahoo(?) contrasts with underlying dark Alapah rocks, probably indicating open-sea shallow-shelf conditions. Dominant crinoidal debris upward in the sequence is interpreted to be biostromal in nature and reflects increased current activity of unknown direction. Little or no clastic material appears to be present; foreland areas may have lain to the north or west.

Permian and Triassic Systems

Sadlerochit Formation

Name and Definition

The Sadlerochit Sandstone was first named by Leffingwell (1919, p. 113-115) after the Sadlerochit Mountains, 15 miles northwest of the Romanzof Mountains. Leffingwell defined the formation to overlie Lisburne Limestone and underlie the Upper Triassic Shublik Formation, and to be composed of ferruginous sandstone or quartzite with a few conglomeratic layers.

Sable (1959) and Bunnell (1959) mapped all rocks between the Lisburne Group and the Shublik Formation in the Romanzof Mountains as Sadlerochit Formation and divided it into the ferruginous sandstone, shale, and quartzite members. This terminology is used in the present report.

Keller, Morris, and Detterman (1961, p. 177), in the Shaviovik-Sagavanirktok Rivers area 90 miles west of the Romanzofs, have divided the Sadlerochit into the Echooka Member of Permian age and the Ivishak Member of Early Triassic age. According to Brosge and others (1962, p. 2194), the term Sadlerochit Formation is now used for all Permian and Lower Triassic rocks within the Brooks Range east of the Ivishak River, and overlies the Lisburne Group with unconformity at most places. Its relationships to the Siksikpuk Formation (Early(?) Permian) (Patton, 1957, p. 41), exposed west of the Ivishak River, are not known.

Distribution and Outcrop

Surface exposures of the Sadlerochit Formation are extensive along the north front of the Romanzofs in an east-trending belt which narrows eastward. The shale and quartzite units are exposed throughout most of the outcrop belt; outcrops of the ferruginous sandstone member occupy a smaller area. Owing to the presence of poorly resistant shaly rocks and because many of the hills comprised of Sadlerochit Formation have not been recently glaciated, the exposures are mostly covered by residual rubble and talus. Good exposures of the ferruginous sandstone member lie on the mountainsides adjoining the Okpirourak Creek, east side of the Okpilak River, and along Old Man Creek and its tributaries. In outcrop, this cliff-forming unit has a pronounced iron-stained aspect. The quartzite 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 due to the lichen covering and the amount of light-appearing shale in the rubble.

Lithologic Character and Thickness

All Sadlerochit rocks in this area are clastic types considered to be deposited in a marine environment, and no carbonate rocks per se are included in the formation, although some sandstones are calcareous. Nearly all of them have been subject to dynamic and low grade metamorphism including silicification. The present rocks are therefore mostly quartzites and slates which, however, are not so severely altered that the primary sedimentary features have been lost.

Ferruginous sandstone 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 unit composed dominantly of medium-dark gray shale and slate. The coarser clastic units are argillaceous and ferruginous due to numerous limonite grains and oxidized pyrite, are generally medium dark-gray, fine-grained to silty, and occur in even beds 6 inches to 9 feet thick. Pebble conglomerates consist of about 70 percent well-rounded gray chert and argillite, 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 range throughout most of the lower unit and are most abundant in the basal part. Fossils are rare to absent in the uppermost unit which contains a variable clay size content and is not everywhere well expressed. Pyritic concretions occur in all three units.

Examination of thin sections shows that sandstones from this member consist of closely packed, well-sorted subangular quartz and minor chert grains in cement of microcrystalline quartz, iron oxides, sericite, and calcite. They are classified as orthoquartzites.

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

Shale member.- Medium dark-gray to black silty and clay shale with about 10 to 20 percent thin interbedded quartzite comprise the shale member of the Sadlerochit Formation. The shale is uniform, laminated and banded, with beds a fraction to 1 1/2 inches thick, and sets of beds as much as 30 feet thick. A few 1- to 2-inch 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, evenly bedded, mostly less than 1 foot thick and weather pale yellowish-brown. The quartzites resemble those in the overlying quartzite member.

Thickness estimates of the shale unit are approximate. The member 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 member grades upward into the quartzite member so that the contact between the two in one part of the area has probably not been drawn at the same depositional horizon elsewhere. The average thickness of the shale member between the Jago and Hulahula Rivers is believed to be about 400+ feet, but apparent thicknesses range from 200 to 650 feet. Farther south, in the southernmost exposures at the head of Old Man Creek, the member 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 part of the ferruginous sandstone member, or to structural duplication of section. The latter possibility was considered likely during field studies, but no evidence for structural dislocation was recognized in this vicinity. Rocks of the member are monotonously similar, and the unit contains no known key beds.

Quartzite member.- Quartzite, lesser amounts of shale and limy sandstone, and minor amounts of granule-to pebble-conglomerate, granule-to pebble-breccia, and clay ironstone constitute the uppermost member of the Sadlerochit Formation. Consisting largely of resistant beds which uphold high ridges and hills, quartzite makes up about 80 percent of the member. The quartzite is medium- to medium dark-gray, fine- to very fine-grained, dense, apparently well sorted and clean, and weathers to grayish and brownish hues. Beds are evenly bedded, average about 2 feet and are as much as 10 feet in thickness, and 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 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%), chert (40-60%) and very fine grained dark rock fragments. Locally, heavy resistates comprise as much as 5 percent of the rock, and include euhedral to well rounded zircon, epidote, sphene(?), tourmaline(?), rutile, and garnet. Quartz overgrowths on quartz grains are locally common. Cement (5-10%) is mostly microcrystalline quartz, chlorite, and sericite.

Gray to black shale and slate, similar to that in the shale member, are interbedded with quartzite and occur in thin sets of beds commonly less than 1 foot thick. Pale brown fine-grained limy sandstone occurs in 6-inch to 2-foot beds. The upper 100(?) feet of the unit is flaggy, ripple-marked, and 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, which are well rounded to subround, fairly well sorted, but poorly packed, consist 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, now mostly weathered to iron oxides, are of scattered occurrence.

The total thickness of the quartzite member is estimated to be about 700 feet. No complete uncomplicated section of this member was found east of the Okpilak River. West of the river, Bunnell (1959, p. 43) reports a minimum thickness of 500 feet and a possible maximum of 800 feet.

Stratigraphic Relationships and Depositional Character

The Sadlerochit Formation overlies Wahoo(?) and Alapah Limestones of the Lisburne Group with disconformity to at least slight angular unconformity in the Romanzof Mountains and is in turn overlain by the Shublik Formation with possible disconformity. No stratigraphic breaks have been recognized within the Sadlerochit Formation 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 inaccessible exposure of the contact in this vicinity.

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

Contacts between members of the Sadlerochit Formation are poorly exposed due to the shaly character of the contact rocks. Relationships between the ferruginous sandstone and shale members appears to be gradational, and the contact is placed between resistant and poorly resistant rocks. The shale and quartzite members are almost certainly gradational or intertonguing, with thin quartzite beds appearing in the upper 100 feet or so of the shale member and culminating in thick massive quartzite beds.

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

The Sadlerochit Formation in the Romanzof Mountains is believed to be entirely a product of deposition in a marine environment. The ferruginous sandstone 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 appear to have lain to the north, as inferred from the apparent northward thinning of the formation to less than 600 feet and the more coarsely clastic nature with coarse conglomerates in the Sadlerochit Mountains (Leffingwell, 1919, p. 113; Whittington and Sable, 1948, p. 8; 1960, p. 34), and the shaly character and presence of limestone in the lower part of the Sadlerochit southeast and southwest of the Romanzofs (Brosge and others, 1962, p. 2193-2194). Mississippian and older metasedimentary rocks probably contributed to the sediments. The shale member was deposited below wave base, and locally abundant pyrite may represent deposition in a euxinic environment. The quartzite member was deposited under shallow shelf conditions, at least in part above wave base, and represents a progressively shallower and more marginal environment upward in the section.

Age and Correlation

Invertebrate faunas found in the Sadlerochit Formation include abundant but poorly preserved spiriferoid, productid, and orthotetid brachiopods in the lower part of the ferruginous sandstone member, one possible pelecypod impression in slate of the shale member, and scattered pelecypod molds and one partial ammonite case in quartzites and limy sandstones of the quartzite member.

Fossils from the ferruginous sandstone member of the Sadlerochit were identified by J. T. Dutro, Jr. of the U. S. Geological Survey, and are shown in table 5.

Table 5. Faunal identifications from the ferruginous sandstone member of the Sadlerochit Formation, Romanzof Mountains, Alaska.

General Location	Field No.	Stratigraphic Position	Identification
Okpirourak Creek	57ASa119	2 to 10 ft. above base	*Spiriferella?* sp.
Okpilak River	58ASa24	34 to 44 ft. above base	echinodermal debris, indet. orthotetid brachiopod, indet. *Anidanthus?* sp. *Spiriferella?* sp.
Tributary of Old Man Creek	58ASa138	within 50 ft. of base	*Spiriferella?* sp.
Tributary of Old Man Creek	58ASa159	unknown	*Anidanthus?* sp. *Waagenoconcha?* sp. *Spiriferella* sp.
Between Okpilak & Hulahula Rivers	58ASa596	unknown	*Spiriferella* sp.

Dutro states:

> "The collections.....contain elements of the Permian brachiopod fauna found in many places in northeastern Alaska. The age is late Early Permian or early Late Permian."

The above fossils 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 P. S. Smith (1939, p. 32), "...Girty is now convinced that it (the lower Sadlerochit fauna) is more properly to be regarded as belonging to the Permian." Dutro

(1956, oral communication), after examination of many Sadlerochit Formation collections, indicates that the lower Sadlerochit fossils are definitely Permian.

An ammonite (Field number 58ASa160, U.S.G.S. Mes. loc. M1028) was collected on the divide between Old Man Creek and Hulahula River drainages about 500 feet above the base of the quartzite member and identified by N. J. Silberling of the U. S. Geological Survey as ? *Ophiceras* (Lytophiceras) cf. *commune* Spath. Silberling notes:

> "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 Lower Triassic and Middle Triassic ammonites, and a younger Triassic age cannot be precluded."

Silberling, in a later written communication (1965) states:

> "...the ammonite fragment questionably referred to *Ophiceras*...might equally well be referred to the genus *Arctoceras* which is a characteristic member of ...mid Lower Triassic fauna in Arctic Canada."

The ferruginous sandstone member is tentatively correlated with the Echooka Member of Keller, Morris and Detterman (1961, p. 177) and the combined shale and quartzite members with their Ivishak Member. The lithologies and stratigraphic position in both areas compare reasonably well, and nothing in the faunal elements contradicts this correlation. The thicknesses of the Echooka and Ivishak Members in their type area is considerably greater than those in the Romanzofs.

Specific lithologic correlations with the Sadlerochit Formation rocks exposed in the eastern Sadlerochit Mountains 25 miles northeast of the Romanzofs (Whittington and Sable, 1948, 1960) are more difficult to make because a higher proportion of sandy and conglomeratic clastics occurs there. The basal 120 feet of their section 6 (1960, p. 79-81) appears to be a coarser lithologic equivalent of the ferruginous sandstone member, and rocks in the upper 455 feet generally resemble the slate and quartzite members.

In the Richardson Mountains and Porcupine River area, Yukon Territory, Martin (1959, p. 2425-2426 and fig. 7, p. 2423) refers a clastic unit at least 2500 feet thick to Gschelian (uppermost Pennsylvanian) and Lower Permian. The Gschelian age designation may have been influenced by the Sadlerochit Formation age given in Leffingwell (1919, p. 115) which is now considered to be Permian. It therefore seems likely that Martin's unit is a Sadlerochit Formation age equivalent; his lithologies include a basal conglomerate, sandstones and sandy shale, and arenaceous and silty limestones in the upper part of the section, and seem to compare favorably with those of the Sadlerochit Formation in northeastern Alaska.

Shublik Formation

Name and Definition

Defined by Leffingwell (1919, p. 116-118) as the sequence which overlies the Sadlerochit Formation and underlies the Jurassic Kingak Formation, the Shublik Formation (Middle to Late Triassic) is a distinctive unit in northeastern Alaska. Its equivalents in northwestern Alaska, although in part lithologically different, display a similar fauna (Smith and Mertie, 1930, p. 185-194; Payne, 1951).

Distribution and Outcrop

Exposures of the Shublik Formation, although of small areal extent, are widespread along the northern front of the Brooks Range (Gryc, in Payne and others, 1951, 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 cut bank of a small stream along the east wall of the Okpilak valley, 1 mile northeast of Okpilak Lake. Elsewhere, except for a few small cut banks and steep hillsides, the formation can be traced only by recognition of rock types in frost heavings and rubble.

Weathered outcrops of most Shublik Formation 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 ironstained, 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 is a persistant 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.

The basal sandstone member, about 40 to 70 feet thick, is medium to dark gray, weathers pale- to moderate-yellowish brown, fine to medium grained, and ranges from calcareous and well indurated to quartzitic. Beds are 1 to 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 to 20 percent of the member. One thin section of phosphatic siltstone in the basal 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 limestones. Sandy limestone beds are blocky to platy, average less than 1 foot in thickness but 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 limonite spherical and ovoid nodules, probably after pyrite, and clay ironstone nodules are relatively rare. Much of the limestone and shale is phosphatic as evidenced by bluish and white efflorescence on weathered surfaces and by chemical analyses. A dark yellowish-orange weathering laminated silty limestone is present in rubble at or near the top of the Shublik in some exposures. The Shublik may be a potential source of rock phosphate (p. 210).

The total thickness of the Shublik Formation may be as much as 700 feet on the east side of the Okpilak River in the section shown by Sable (1959, p. 64-67). About 665 feet of this section is ascribed to the limestone member. Bunnell (1959, p. 46 and 48) indicates about 70 feet for the sandstone member and about 550 feet for the limestone member 3 1/2 miles west-southwest of the above 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. The quartzite beds of the overlying Jurassic Kingak Formation also represent an abrupt change back to dominantly clastic-type deposition. 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 Romanzofs, occur in the British Mountains (Maddren, 1912, p. 18-19). To the west, the Shublik Formation consists mostly of shale, light sub-lithographic limestone, cherty limestone, and bedded chert. All sections which can be confidently ascribed to the Shublik Formation do not exceed a few hundred feet in thickness.

Age and Correlation

The Shublik is locally very fossiliferous. Fossils appear to be abundant near the middle and at the top of the limestone member and scattered throughout the upper half, but none were found in the lower part of the formation. Fossils consist of monotid-type pelecypods, rhynconellid and terebratuloid brachiopods, belemnite and nautiloid fragments, and gastropods. Shell material appears to be either phosphatic or calcareous. In addition to many localities in which Monotis cf. M. subcircularis Gabb and Halobia cf. H. cordillerana Smith were identified by the author, identifications of three collections by N. J. Silberling, U. S. Geological Survey, are shown in table 6.

Table 6. Faunal identifications from the Shublik Formation, Romanzof Mountains, Alaska.

General Locality	Field No.	Stratigraphic Position	Identification
Mountain front, Okpirourak River	57ASa13	in upper one-third	Halobia sp., indet.
2 1/2 miles W-NW 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 indicates a Late Triassic age for the first collection, and a late Late Triassic (middle or late Norian) for the other two. Reexamination of collections by Silberling (written communication, 1965) in northeastern Alaska, including one collection of Karnian age from the Romanzof Mountains, indicates to him that the Shublik in northeastern Alaska ranges from Ladinian (late Middle Triassic) through Norian in age.

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 include about 4000 feet of black concretion-bearing shale in its type area. 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 area (Gryc and Mangus, 1947; Mangus, 1953; Keller, Morris, and Detterman, 1961). Many of the exposures reported by Leffingwell have been re-examined and megafossil and microfossil information from the formation have been published (Imlay, 1955; Tappan, 1955).

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.

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

Lithologic Character and Thickness

Kingak rocks in this area are divided into a thin basal siltstone member and a thick overlying black shale member as earlier reported by Sable (1959, p. 70) and Bunnell (1959, p. 50).

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- to medium dark-gray and olive gray, weather light brown, are evenly bedded, 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. Scattered subround to irregular dark-gray phosphatic pebbles or nodules are as much as 2 1/2 inches in diameter, and argillaceous pellets are scattered along bedding planes. A few calcareous shell fragments (pelecypods?) are present in the limy sandstone.

Although the probable maximum thickness of the siltstone member is about 75 feet along the Okpilak River, incomplete exposures of this unit along Okpirourak Creek drainages and west of the Okpilak are at least 150 feet thick and 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 far to the north of basal Kingak beds, although little of this rock type is exposed near the Romanzof Mountains. A few outbank 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 in the Romanzof Mountains is unknown, but is probably more than 1000 feet.

Stratigraphic Relationships, Age, and Correlation

The Kingak Shale is too poorly exposed in the Romanzof area to permit an interpretation of its inter- or intrarelationships. The lack of identifiable fossil remains precludes statements regarding the age of the Kingak beds in the area. The abrupt change from the phosphatic organic shale and limestone of the Shublik Formation to the variable thicknesses of clastic rocks in the basal part of the Kingak may indicate an erosional or nondepositional break before deposition of Kingak beds. Likewise, the presence of rounded phosphatic "pebbles" in parts of the siltstone member of the

Kingak suggests that these may be pebbles derived from older Shublik beds. In general, basal Kingak deposition was probably more rapid than that during Shublik time, as shown by the larger proportion of coarser clastic material and absence or scarcity of primary phosphatic material. Deposition was also probably below wave base; bedding features indicative of wave or current activity were not seen. The widespread distribution of the shales and presence of marine fossils elsewhere in northeastern Alaska points to a marine origin, perhaps in a deep restricted basin, or in a sinking basin adjacent to a slowly rising source area of relatively low relief. Source areas for these rocks is unknown; farther west, source rocks for Jurassic Tiglukpuk Formation (Patton, 1956, p. 213-218) graywacke-type sediments are interpreted to have lain to the south, and an interpretation by Keller, Morris and Detterman (1961, p. 191) is that the upper part of the Kingak Shale represents a more northerly offshore equivalent of the graywackes. They state that the Kingak Shale may be characterized by overlap relationships or unconformities (1961, p. 193), previously suggested by Imlay (1955) on the basis of faunal evidence. If the phosphatic pebbles in the siltstone member of the Romanzof area represent reworked Shublik Formation rocks, it would seem that this, plus the marked change in sedimentation may provide evidence for an erosional break. The siltstone member of the Kingak might be interpreted to represent initial clastic influx from a slowly rising eastern or southern source followed by downwarping, marine transgression, and deposition of the thick black shale member. Contemporaneous thick graywackes accumulated in an east-trending belt southwest of the present Romanzofs, but the eastern continuation of this belt south of the Romanzofs has not been proved. Thick Jurassic shales and sandstones in the Richardson Mountains of the Yukon Territory are reported by Martin (1959, p. 2428).

First classified as Lower Jurassic by Leffingwell (1919, p. 119-120), the Kingak Shale and probable equivalents were later placed in the Middle and provisionally Lower Jurassic by P. S. Smith (1939, p. 46). Fossils from the Kingak Shale elsewhere in northeastern Alaska, have been more recently reported by Imlay (1955) to represent parts of the Pliensbachian and Toarcian stages of the Lower Jurassic, the Bajocian and Callovian of the Middle Jurassic, and the Oxfordian and Kimmeridgian of the Upper Jurassic. Several breaks during Middle and Upper Jurassic time are suggested by Imlay.

The few shell fragments found in the siltstone member of the Kingak Shale are too fragmental to yield age-information. Basal Kingak beds reported by Whittington and Sable (1948, p. 11-12) on the Sadlerochit River, with which the siltstone member is correlated, contain pelecypods, including Gryphea cf. G. cymbium Lamarck, of probably early Jurassic (Pliensbachian?) age (Imlay, 1955, p. 73).

Cretaceous(?) System

Ignek(?) Formation

A poorly-exposed sequence consisting of sandstone, shale, and coaly beds tentatively correlated with the Ignek Formation, crops out in low whaleback ridges along Okpirourak Creek about 3 miles northwest of Jago Lake, and along the Jago River, 9 miles downstream from Jago Lake. Other exposures in the foothills north of the Romanzofs, delineated from aerial photograph study are provisionally mapped as Ignek(?) (pl. 1). The Ignek Formation, first described by Leffingwell (1919, p. 120-125) contains similar lithologies as well as a marine or transitional fossil fauna in part of the formation. 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). The exposures in the area here described, however, are unfossiliferous except for small 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 glacial and glaciofluvial deposits.

The exposures on Okpirourak Creek consist of at least several hundred feet of poorly-exposed 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 ironstain. It is very fine- to medium-grained, weathers platy to flaggy, and contains scattered carbonized wood fragments. Small ripple marks and scour markings were observed 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 from a sandstone in the Okpirourak Creek exposures indicates the rock to be a lithic graywacke. Poorly sorted as to type and size, sub-angular 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 with 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, according to John E. Cantlon, who procured specimens of these rocks. These exposures lie along the same general strike as the Okpirourak Creek exposures, and are considered to be roughly equivalent to the latter.

Leffingwell (1919, p. 120) estimated about 2500 feet of strata to comprise the Ignek Formation in its type area. Keller and others (1961, p. 203-207), have subdivided the Ignek into an upper member in part of Late Cretaceous age, and a lower member of late Early Cretaceous age, and imply an unconformity between the two members. Incomplete sections of their lower member are as much as 2590 feet thick; the upper member may be several thousand feet in thickness.

Fossil collections of Leffingwell and later workers examined by Imlay (1961, p. 30) contain species characteristic of late Early Cretaceous (Albian) age. Thick graywackes and shales of early Early Cretaceous age, which are well developed north of the Brooks Range in north-central and northwestern Alaska, are not present in northeastern Alaska where Ignek Formation overlies Upper Jurassic (Oxfordian) rocks (Imlay, 1961, p. 5).

About 3000 feet of early to middle Lower Cretaceous rocks are reported in the Richardson Mountains, northern Yukon Territory (Martin, 1959, p. 2430). Martin emphasizes the difficulty of distinguishing Lower Cretaceous and Jurassic beds on lithologic grounds. The boundary between the Kingak Shale and Ignek Formation in northeastern Alaska may also be of similar nature. An unconformity below Early Cretaceous rocks is strongly indicated in northwestern Alaska, however (Dutro and others, 1951, p. 14).

Quaternary System

Pleistocene and Recent glaciation has resulted in striking depositional and erosional features in and north of the Romanzof Mountains similar to those in the central Brooks Range. 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 present glaciers in northern Alaska. Most of the present larger glaciers, remnants of earlier extensive glaciation, are 3 to 5.5 miles in length and compound, but several are relatively simple, and suited to glaciological studies such as that carried out during the 1957-58 International Geophysical Year on McCall Glacier (Mason, 1959; Sater, 1959). Aside from well-developed U-shaped and hanging valleys, recently and presently occupied cirques, arêtes, simple to complex ice-fracture patterns, and faceted spurs and trim lines, ice-contact and glaciofluvial deposits extend along most of the tributary streams, the major river valleys, and in inter-stream 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 evidenced mainly from position, degree of modification (by erosion, frost action, and weathering), and degree of vegetation encroachment on moraines and outwash. A few indications of cross-cutting relationships of valley glacier features are also present where tributary streams enter major valleys. Other than the glacial features, Recent materials consist of present 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 wind-blown 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.

Glaciation

Pertinent Brooks Range Glacial Investigations, 1907-1960

Leffingwell (1919, p. 133-136, 156-157) discussed observations of Pleistocene and Recent glaciation along the Okpilak and Hulahula Rivers. On the basis of truncated spurs along the Okpilak valley, he concluded that the ice thickness was nearly 3000 feet at the major forks of the Okpilak River, but that the advance extended only 10 to 12 miles north of the mountain front. Glaciers extending much farther north to the northwest of this area, however, were suggested by Leffingwell (1919, p. 137, 140), although he saw no evidence for piedmont glaciation and implied that one Pleistocene ice advance probably took place. He recognized a Pleistocene till-like deposit along the Arctic Coast north of the Romanzof Mountains (1919, p. 142-149) but was uncertain of its origin.

Detterman (1953, p. 11-12) established the first glacial nomenclature in and north of the Brooks Range. He recognized four glacial advances in the Sagavanirktok-Anaktuvuk region approximately 120 miles west-southwest of the Romanzof Mountains, which he named, from oldest to youngest, the

Anaktuvuk, Sagavanirktok, Itkillik, and Echooka glaciations. The older two were defined in separate areas. Detterman, Bowsher, and Dutro (1958) extended these names farther west and named two younger glaciations: Alapah Mountain and Fan Mountain glaciations. All were considered to be of Pleistocene age, except the latter, probably of Recent age. In addition they state (1958, p. 51) that Anaktuvuk and Sagavanirktok glaciations may represent a single advance.

Kunkle (1958) mapped the glacial geology of a portion of the Jago River valley north of the mountain front, and made scattered observations farther south along the Jago and its tributaries and in the Okpilak River valley. He recognized six ice advances which he correlated with the sequence of Detterman, Bowsher, and Dutro.

Keeler (1959) reports on observations along McCall Glacier and McCall Creek valley. On evidences of morphology, geographic distribution, and geomorphic features, evidence for five glacial advances is cited by him, and he suggests correlations with the central Brooks Range sequence.

Sable (1961), by comparison of Leffingwell's 1907 photographs of the Okpilak Glacier with later aerial and field photographs, recognized a very recent stage of glacial retreat resulting in two sets of end or recessional moraines, both of which he correlated with Fan Mountain glaciation. He also calculated approximate degree and rate of retreat and thinning of Okpilak Glacier since 1907.

In the Mount Chamberlin area, 15 to 25 miles west of Okpilak River, Holmes and Lewis (1961) recognize 5 glaciations, for which they propose a new terminology. Their tentative correlation with Detterman and others (1958) is as follows:

	Holmes and Lewis (1961)	Detterman, Bowsher, & Dutro (1958)
Recent	Cirque Moraine II Cirque Moraine I	Fan Mountain
Pleistocene	Peters	Alapah Mountain
	Schrader	Echooka
	Chamberlin	Itkillik
	Weller	Sagavanirktok Anaktuvuk

Holmes and Lewis state that correlation with Fan Mountain and Alapah Mountain are fairly certain, and imply a fair degree of correlation confidence between Echooka and Peters on the basis of physical expression and presence of large lakes behind the end moraines. They express more uncertainty about Itkillik and Chamberlin equivalence because Chamberlin moraine appears more highly modified than the type Itkillik drift farther west. Their correlations with the earliest glaciation(s) is uncertain.

The Quaternary geology shown on plate 1 and discussed here results from numerous but scattered observations made by the writer, Kunkle, and Bunnell, augmented by examination of aerial and field photographs by the writer. Kunkle's map units and conclusions have been incorporated in modified form by the author, who disagrees with some of Kunkle's interpretations. The writer feels that the new terminology of Holmes and Lewis in the Mount Chamberlin area is preferable to Kunkle's use of western names. Despite the similarity in climate, differences between the dominant bedrock types in central and eastern Brooks Range source areas might be reflected by morphologic differences in their glacial products. Morainal material along the Okpilak and Jago valleys is mostly composed of granitic constituents, while those in other northern Alaskan areas are reported to contain little or none. The moraines as much as 6 miles north of the mountain front along these valleys, although modified to different degrees, are very well defined.

The writer recognizes 5 major units of glacial depositional and erosional features in the area, which, in morphology, position, and degree of vegetation encroachment appear to be distinct enough to relate them to separate glacial advances. They reflect successively shrinking glaciers, as previously recognized by other investigators in the Brooks Range. Uncertainties exist, however, in the precise delineation and correlation of units from place to place. Along the major river valleys and in 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 cross-cutting relationships, if present, are obscure. Within the mountains some cross-cutting relationships are present in places where tributary glaciers have overridden older trunk-glacier moraines, but detailed relationships of tributary glaciers to the main valley glaciers are still unknown.

The correlations of Kunkle and Keeler as related to the terminology of Holmes and Lewis and of Detterman and others farther west are not wholly consistent, although all workers use similar criteria in differentiating glaciations or glacial advances. Kunkle (1958, p. 30) refers to an end moraine on McCall Creek as Alapah Mountain, which Keeler (1959, p. 92) correlates as an Echooka recessional moraine. Moraines referred to the Itkillik glaciation by Kunkle (1958, p. 21) appear to be similar to the Schrader moraines of the Mount Chamberlin area which are tentatively correlated with Echooka glaciation. Because of these apparent discrepancies, and because the present writer is uncertain of possible equivalents, he is reluctant to indicate correlations with the previous terminologies, except for the oldest and most recent deposits. He does feel, however, that major glacial advances in the eastern Brooks Range were probably synchronous with those in the central Brooks Range, but that differences in source-area bedrock may produce morphologic forms of different ages but of similar gross appearance.

Deposits of the five advances are differentiated on plate 1; form-lines also indicate the approximate outer limit of prominent moraines.

First Advance

Features.- Deposits which occur at the northern limits of the area and at least one mile farther north, are attributed to the oldest known advance, and are tentatively correlated with the Weller glaciation of Holmes and Lewis. They include scattered erratics in tundra-covered lowland areas without observable morainal traces. Lakes and ponds are rare and have been mostly filled, drainage is well integrated, and numerous well-drained areas with bedrock traces and outcrops indicate that the deposits are probably thin, In some interstream areas, 2 1/2 miles southwest of Jago Lake, highly weathered "rotten" granite erratics are attributed to this advance, as well as 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 valley, altitudes of the approximate upper limit of glaciation as inferred by the highest granite erratics in areas of bedrock are 3500 feet west of, 3700 feet one mile southeast of, and 3800 feet 3 1/2 miles southwest of Okpilak Lake, respectively. Southward, erosional features in granite terrain include truncated spurs, the tops of which lie at 5000 to 5200 feet between Leffingwell and Dark Creeks, about 5300 feet 4 miles south of Leffingwell Creek, and 6100 feet 2 miles southwest of the main Okpilak River forks.

Along the Jago River glacial erratics occur up to about 3200 feet altitude at the mountain front, although ice from the McCall Glacier reached about 3850 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 4000 to 3400 feet altitude, is thinly veneered by boulders and tundra vegetation. The writer essentially agrees with Keeler, who first described this feature (1959, p. 91), that the bench, corresponding in altitude with the pass and with the highest morainal material along the Jago River, marks the approximate upper limit of glaciation in this vicinity. Southward along the Jago River valley, erratics occur up to about 3400+ feet 1/2 mile south of McCall Creek and 3500 feet one mile farther south. Tops of modified faceted spurs 7 and 10 miles south of McCall Creek are at 4000 and 4800 feet respectively.

The First advance was obviously of piedmont type. South of the mountain front it was essentially 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, so that the two small mountain masses flanking the Jago valley stood as nunataks above the ice.

Correlation.- Kunkle correlated this glaciation with the Anaktuvuk glaciation of Detterman and others. In the McCall valley, Keeler correlated it with either the Anaktuvuk or Sagavanirktok glaciations.

Second Advance

Features.- The Second advance is represented by recognizable but 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 are generally smooth-surfaced, 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 encroached on by tundra vegetation except along their crests where vegetation is patchy, and well developed patterned ground features are common.

Several moraines, interpreted to be recessional, are present on both the Okpilak and Jago Rivers (pl. 1), and 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 3300 feet west and southwest of Okpilak Lake (fig. 5) and 4000+ feet 6 miles farther south. Along the Jago River, rough upper limits of similar boulder concentrations occur along McCall Creek at about 3600 to 3300 feet altitude (Keeler, 1959, p. 91), and about 3000 to 3500 feet along the Jago River 1 to 4 miles south of McCall Creek.

Although major tongues of this advance probably coalesced to come extent in interstream areas 5 to 6 miles north of the mountain front, it is doubtful that a continuous piedmont cover was present. Outwash from the trunk glaciers probably did coalesce and determined the course of Okpirourak Creek

Figure 5. Oblique view 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 Kingak Formation quartzite (Jk). Tight folds of Sadlerochit Formation quartzite member in left foreground. Photo by U. S. Navy.

north of the mountains. Ice, if it did flow through the pass north of McCall Glacier (Kunkle, 1958, p. 20-21) was thin. Likewise, the low area east of McCall Creek, where patchy bouldery drift occurs at 2900 to 3000 feet, was probably only slightly overridden.

Correlation.- Kunkle considered deposits of this advance 6 to 9 miles north of Jago Lake to be correlative with the Sagavanirktok glaciation. His northern limits agree generally with those of the Second advance but the latter 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 glaciation. The writer recognizes only subtle differences between the northern exposures of Kunkle's Itkillik deposits and southern exposures of Kunkle's Sagavanirktok 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 miles and 6 miles north of the mountain front along the Jago and Okpilak Rivers respectively. 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. Thin tundra vegetation occurs in lowland areas but knobs and ridges are relatively bare. Along the Okpilak River similar topography is present 4 to 7 miles north of Okpilak Lake, where several moraines converge on the river; the northernmost corresponds to a strong 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 mass-wasting resulting in mixed morainal material, and because lateral moraines from tributary glaciers 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 2700 feet altitude. Trim lines at 3000, 3500, and 4000 feet 4, 7, and 11 miles respectively south of Okpilak Lake, approximately correspond to the apices of the highest alluvial and talus fans in those vicinities. Along the Jago River, tops of lateral moraines as traced southward from the end moraine are at about 2200 feet altitude at the mountain front and perhaps at 3000 feet 11 miles south. Moraines 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 their surfaces.

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

The difference in position between the limits of the Third advance on the Okpilak and Jago Rivers is based partly on the assumption that the glacier regimen during this and succeeding advances was similar although larger in scale to the present regimen. At present, the ice volume of glaciers drained by the Okpilak River is greater than the volume of those drained by the Jago, although the Jago has the larger drainage area. Furthermore, many of the Jago River glaciers are south of this report area, and it is doubtful that they reached the northern part of the Jago valley. The Okpilak valley is of similar dimensions to the Jago valley in this map area. It follows then, that the Okpilak valley had a larger volume of ice, which resulted in more northerly positions of equivalent advances and recessions than in the Jago 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 to beyond Okpilak Lake in the Okpilak valley, and a similar one in the Jago valley which did not reach the mountain front. Evidence for the extent of this glaciation along the Okpilak valley includes a single-crested well-developed lateral moraine 200 to 300 feet above the river 8 to 13 miles south of Okpilak Lake (fig. 6,A). Tributary moraines attributed to this advance extend from Dark Glacier and Leffingwell Glacier into the valley at slightly higher altitudes and parallel the main lateral moraines. These can be traced intermittently along the west valley wall as far north as 1 1/2 miles north of Okpilak Lake and appear to correlate with moraines which close on the river about 4 miles north of Okpilak Lake.

Along the Jago River, glacial deposits along Boulder Creek are keys to understanding the Fourth advance. An end moraine ascribed to Fourth advance extends over older glacial deposits at the mouth of the creek (pl. 1). Correlation of this moraine with the end moraine 1 1/2 miles upstream from McCall Creek mouth is 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

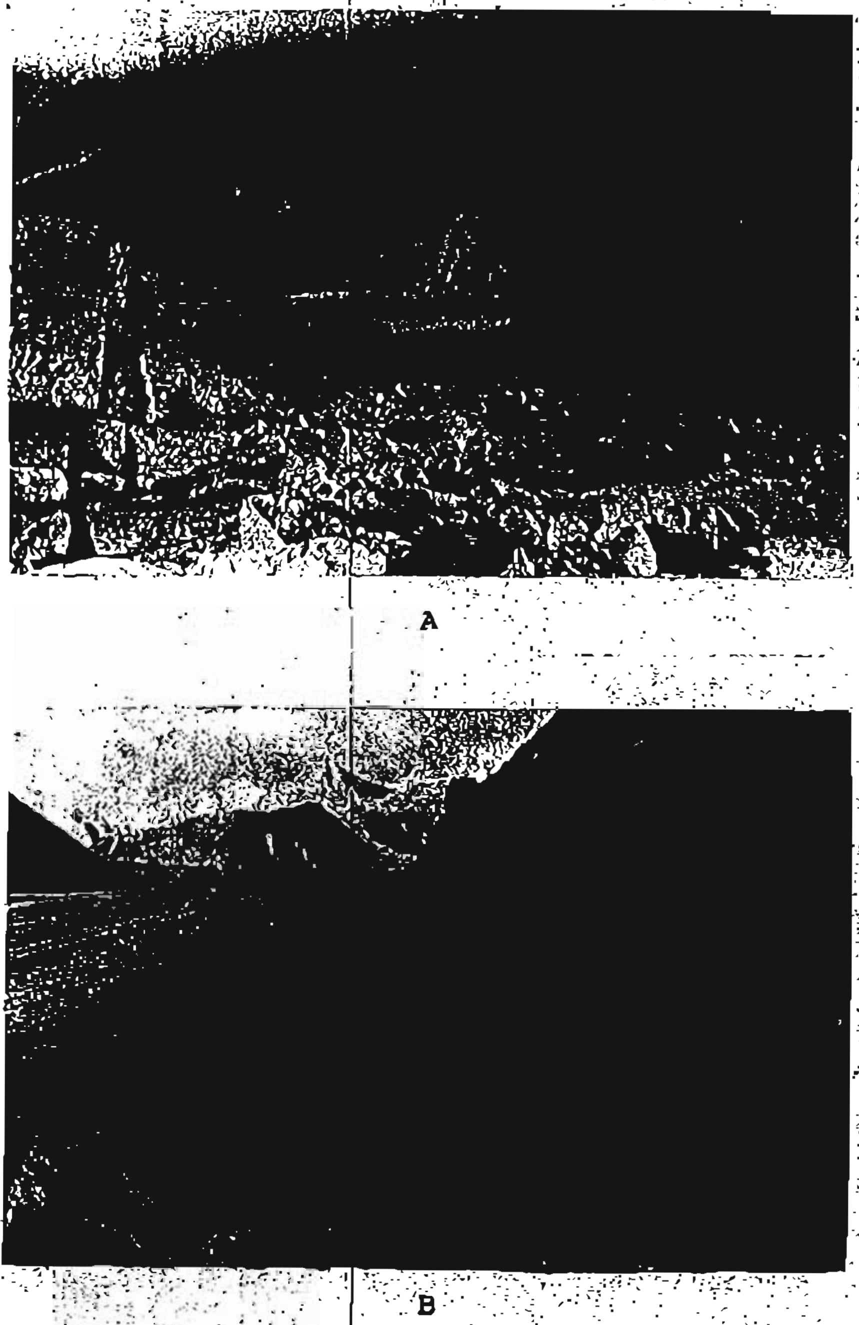

Figure 6. Glacial, alluvial, and colluvial features in the Romanzof Mountains.

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.

Valley north of Boulder Creek. Three to 9 miles south, however, lateral moraines about 250 feet above the river are well preserved and probably extend even farther south beyond observed limits.

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 upstream lateral moraine along each of the creeks which drain Leffingwell, Dark, McCall and Hubley Glaciers occur above 1, 1 1/2, 3 1/2, and 2 1/2 miles respectively upstream from their mouths. A tributary moraine cutting terminal moraines of the Fourth advance also occurs about 2 miles above the mouth of Boulder Creek. These are interpreted to be recessional moraines of the Fourth advance or to represent a readvance. These moraines are intermediate in stability and amount of vegetation cover between those of Fourth and Fifth advances, and may be more closely related in time to the Fifth advance than to the Fourth advance end moraines.

<u>Correlation</u>.- On the Okpilak River Kunkle considered the converging moraines 3 to 4 miles north of Okpilak Lake

(here, the approximate limits of Second advance) as Itkillik recessional moraines, although he states (1958, p. 25) that he had previously considered the moraine 3 miles north of the lake as a younger Echooka end moraine. He therefore considered Echooka glaciation to have reached only as far north as Okpilak Lake. However, only one paired depositional terrace was noted above the present floodplain terrace in the Okpilak Lake vicinity, whereas two distinct terraces are present within Kunkle s Echooka glaciation limits on the Jago River. The writer interprets this to indicate that, despite the outward similarity of the paired lakes along these river valleys, those along the Okpilak River lie within limits of a glacial advance younger than that on the Jago.

Kunkle correlates end moraines of this advance along McCall and Boulder Creeks with Alapah Mountain glaciation. Keeler (1959, p. 92) indicates that the McCall Creek moraine is an Echooka recessional moraine, but the writer recognizes it as a true end moraine representing a separate advance.

Fifth Advance

The youngest glacial advance, relatively minor, very recent, and probably of short duration, is correlated with Cirque Moraines I and II and Fan Mountain glaciation. One terminal moraine (Cirque II) adjoins all present glaciers. An end moraine (Cirque I) commonly occurs as much as 1000 to 2500 feet downstream from most of the larger glaciers and is commonly separated from Cirque II terminal moraine by meltwater deposits and aufeis. Both moraines are fresh and unstable, and those of Cirque I locally support a few alpine plants. Upglacier, lateral moraines of Cirque I and II are probably indistinguishable (fig. 6,B). At higher altitudes, trim lines corresponding with tops of Cirque I 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 by Sable (1961) indicate that Cirque I and II glaciation probably occurred in recent historic time. All glaciers observed in the Romanzof Mountains show similar features, and small evacuated cirques also contain fresh deposits of this glaciation. This advance did not reach the major river valleys except in their headwaters.

Age and Correlation Summary

Table 7 is intended primarily to show tentative correlations between this area and the Mount Chamberlin area 20 miles to the west. Central Brooks Range terminology is also included because Holmes and Lewis attempted provisional correlation with that region and because Kunkle also used central Brooks Range terminology. Kunkle's usage, however, is shown relative only to that of the present paper.

Correlation of the Fifth advance with Cirque Moraines I and II is quite certain. Fourth advance, at least within the mountains, is similar in respect to size, position, and degree of modification to Peters glaciation. Third advance with its modified knob and kettle topography north of the

Table 7. Quaternary Chronologies in the Brooks Range, Alaska.

Detterman, Bowsher & Dutro (1958)	Holmes and Lewis (1961)	Kunkle (1958)		This paper
Central Brooks Range	Mount Chamberlin Area	Okpilak River	Jago River	Okpilak and Jago Rivers
FAN MOUNTAIN	CIRQUE II CIRQUE I		FAN MOUNTAIN	Fifth Advance
ALAPAH MOUNTAIN	PETERS	? ECHOOKA	ALAPAH MOUNTAIN	Fourth Advance
ECHOOKA	SCHRADER	ITKILLIK (Map, p. 38)	ECHOOKA	Third Advance
ITKILLIK	CHAMBERLIN	SAGAVANIRKTOK (Map, p. 37)	ITKILLIK SAGAVANIRKTOK	Second Advance
SAGAVANIRKTOK ? ANAKTUVUK	WELLER	ANAKTUVUK	ANAKTUVUK	First Advance

mountains is probably equivalent to Schrader glaciation, but the equivalency of its northern limit is uncertain. Second advance, in its morphologic forms and drainage pattern appears to resemble both Schrader and Chamberlin glaciations. First advance is correlated with Weller glaciation on the basis of morphology and weathering character.

The most pronounced differences in present form and weathering of the deposits appear to be between the First and Second advances. No suitable material for age dating was seen, 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 consider Weller glaciation pre-Wisconsin, and the remaining glaciations, except for Recent Cirque Moraines I and II, as presumably Wisconsin.

Adjacent Areas and Isolated Deposits

East of the Jago River, deposits beyond the mountain front include strong morainal traces similar to those of the Second advance to 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 (pl. 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 Okpilak River, there are scattered granite erratics along Old Man Creek, but no concentrations were observed. 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 studied in the field. Binocular examination and aerial photograph studies, however, indicate well-defined morainal traces to as high as 2500 feet altitude and 1300 feet above the river, extending northward beyond the area and converging about 15 miles north of the mountain front. Their surface expression is similar to either or both Second and Third advances. The writer infers that they are correlative with Second advance or Chamberlin glaciation.

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

Alluvial and Talus Fans

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

Several fans examined in the upper part of the Okpilak valley show features indicating three stages of activity (fig. 6,A). The oldest and usually marginal portion of the fan is stable, slopes average 10° to 20°, and fan material is nearly covered by rock lichens and patchy tundra vegetation. In some fans, the oldest portion 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 is barely stable under a man's weight, and 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. It's pattern of encroachment is similar to that of the intermediate stage; it forms the apices of active fans and occurs down to present river level.

Deposits in a fan 1 1/2 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 include about 30 percent granite boulders as much as 3 1/2 feet, and averaging 2 feet in diameter; 20 percent cobbles (granite and minor limestone); 20 percent pebbles (80% granite, 20% quartz and limestone); and 30 percent sand (90% quartz, 10% feldspar and dark minerals). No stratification, soil layers, or other evidence for separating the fresh material was observed, although dissection cuts into pre-modern fan deposits.

GRANITIC ROCKS

Names and Terminology

The name "Okpilak" gneissoid granite has been used informally (Whittington and Sable, 1948) to designate the main granite mass between the Jago and Hulahula Rivers (pl. 1). In this paper a more inclusive name, Romanzof granite, is here proposed to include all granitic rocks in the Romanzof Mountains. The names Okpilak batholith and Jago stock, here used for the two larger bodies of granite in the area (pl. 1) respectively designate the main exposed mass of the pluton 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 subsurface continuation.

The compositional classification for the granitic and mafic rocks is modal and is modified from Johannsen (1931, vol. 1). 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 it includes granite gneiss, schistose rocks of granitic composition, and other granitoid rocks. Grain-size terms for granitoid textures follow those of Johannsen (1931, vol. 1, p. 31). Melt refers to a wholly fluid or mixed crystalline and fluid mass in which plastic crystalline flow is possible. Metasomatism implies volume-for-volume replacement of material in a partially or wholly solidified mass; distances of transport are not implied. Primary is used to denote textures and structures interpreted to have formed during a stage of plastic crystalline flow or to represent features of granitized rocks which are older than their present crystalline fabric. Secondary refers to textures and structures interpreted to have been superimposed on the pluton after emplacement.

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. The 1948 U. S. Geological Survey party examined 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). It was suggested that the pluton may have been emplaced prior to Mississippian time, and samples of the granite were shown to be markedly radioactive (White, 1952).

The 1957-1958 field investigations reported on here are considered to be of semi-reconnaissance nature in that large interareas between linear traverses were not examined, although limited areas were carefully studied. The most concentrated observations were made along the Okpilak River and its tributaries; less time was spent in the Jago and Hulahula drainages. At the stations occupied during field work, 175 samples ranging from 1 to 6 specimens each, were taken and all recognizable planar and linear rock features were recorded. Fifty standard thin sections were examined, and some minerals were identified by oil-immersion methods on crushed fragments. Identification of plagioclase feldspars was made 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 includes 21 modal analyses made by the author using the method described by Chayes (1949), and 6 chemical analyses by the U. S. Geological Survey. Age determinations on two samples of granitic rocks were made by the U. S. Geological Survey.

Distribution and Outcrop

The Romanzof granite is exposed in two main areas 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; the Jago stock, along the Jago River 13 to 18 miles south of Jago Lake, is about 16 square miles in area. Three small areas are exposed north of the Okpilak batholith in the headwaters of Okpirourak Creek. A smaller exposure of granite, about 1000 square feet in area, is present in the alluvial fan at the mouth of McCall Creek. This is interpreted to represent an isolated bedrock outcrop, but may be an unusually large glacial erratic. Other small exposures of granite are present about 1/4 mile east of the Jago stock along the sole of an overthrust plate.

The Romanzof granite forms the highest and most rugged part of the Romanzof Mountains. Bedrock exposures are estimated to comprise about 50 percent of the granitic areas; glaciers and their depositional products, snowfields, talus, and alluvium cover the remainder. The best exposures occur on mountain slopes and ridges, in cirque walls, and along small tributary streams and dry washes. Of the major rivers, only the upper part of Okpilak River is incised in granite. Below altitudes of about 6000 feet, bedrock is largely covered by rock lichens and here fresh stream cuts or unstable slopes provide the best exposures. Above this altitude, exposures are clean but many are inaccessible.

Lithology and Composition

The Romanzof granite is megascopically a dominantly light- to medium light-gray, medium- to coarse-grained granitoid rock containing essential potash feldspar, quartz, plagioclase feldspar, and fresh to chloritized biotite in decreasing order of abundance. Seriate textures include porphyritic types with large potash feldspar megacrysts; gneissoid, gneissic, autoclastic(?) and cataclastic textures are common, and schistose granite is locally abundant. Equigranular textures occur mostly in the interior portions of the pluton but 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 only a few localities. Black tourmaline is locally common in several types of occurrence. Disseminated pyrite is locally abundant; recognizable magnetite, molybdenite, muscovite, sericite, and fluorite are less common. "Pink-and-green" granite, in which potash feldspar and plagioclase are respectively these colors, comprises a very minor fraction of the pluton and is not considered a separate granite facies but is probably the result of deuteric alteration or later mineralizing effects. Dark dikes include quartz-monzonite and mafic rocks. 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 Romanzof granite are perthitic microcline, quartz, plagioclase and titaniferous(?) biotite. Hornblende is rare. 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.

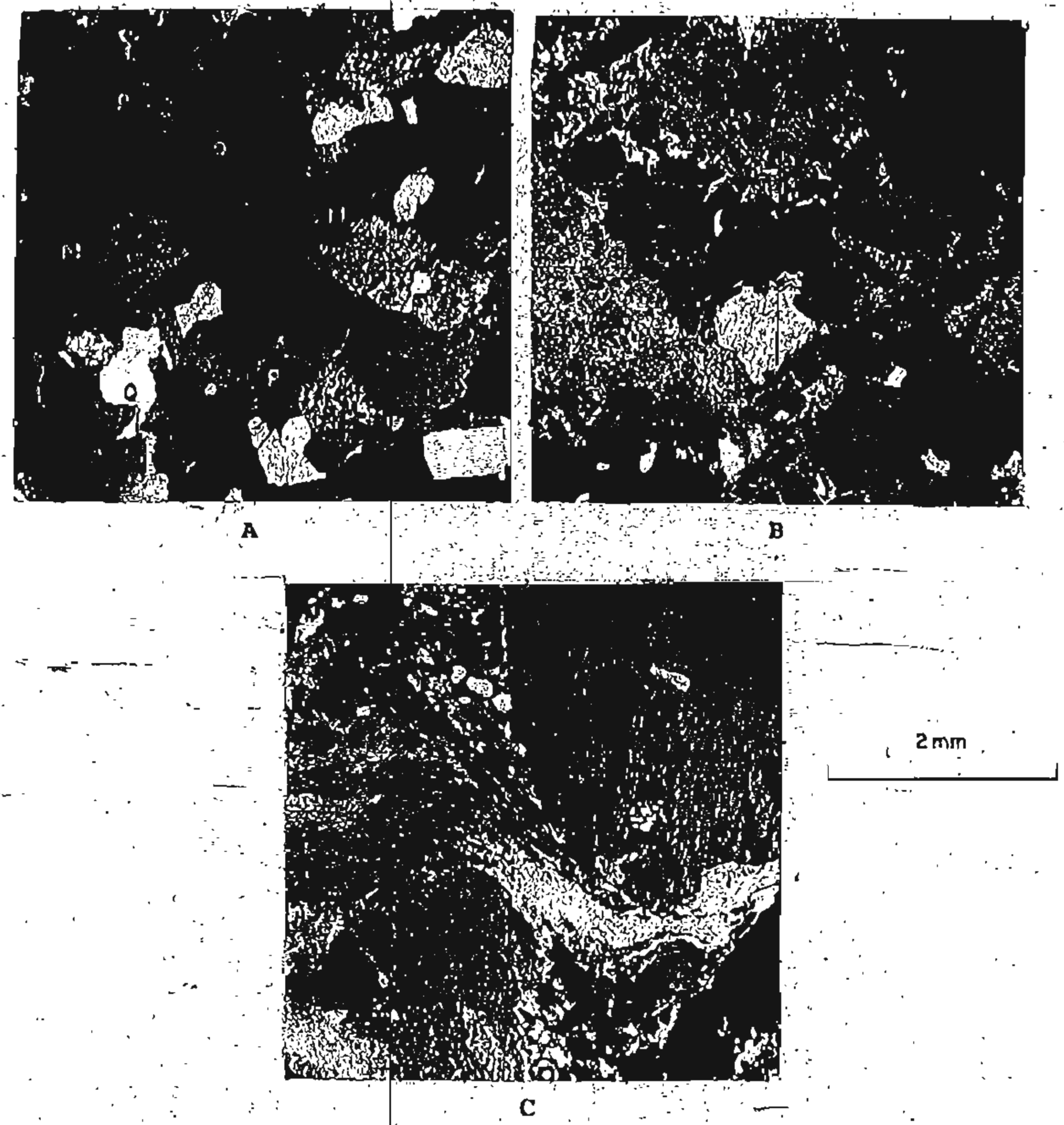

Figure 7. Photomicrographs of textures in Romanzof granite. Crossed polars.

A. Anhedral-equigranular texture along Jago River tributary. M, Microcline; Q, quartz; P, plagioclase.

B. Schistose granite on east side of Okpilak River. Area on left is a mixture of sericite, chlorite, and quartz.

C. Shear zone between microcline megacrysts composed of sericite, shredded biotite, and quartz. Okpilak River, east fork.

Microcline. Microcline occurs as large ovoid to euhedral megacrysts characteristic of the porphyritic textural facies (p. 128), and as anhedral to euhedral groundmass grains. It is predominantly perthitic, commonly containing 5 to 30 percent albite, and is in small part granophyric. Zonally arranged inclusions of quartz occur within many crystal margins. 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 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, altered to kaolinite, shows wavy extinction, and common Carlsbad twinning. The gridiron twinning ranges from well developed to very obscure. Quartz veinlets cut microcline in some sections.

The rounded edges and corners of microcline megacrysts in thin section are commonly bounded by equigranular micro-aggregates 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 be the result of movements in the late stages of, or after, their crystallization.

Partial alteration of potash feldspar to kaolinite is common. In some sheared zones, the megacrysts show degrees of mineralogical alteration from fresh microcline to flattened greenish or whitish "ghosts" composed entirely of chlorite and/or sericite and quartz (fig. 8). Microcline also occurs more rarely in veinlets intergrown with quartz, calcite, and epidote; no perthitic intergrowths were seen in this variety.

Plagioclase. In the Romanzof granite, plagioclase is generally subhedral, occurs mostly in the groundmass, but also as larger nearly euhedral single or interlocking crystals. Its composition is mostly albite and oligoclase (An_6-An_{12}, mostly An_8). Plagioclase in small groundmass grains appears to be more sodic than 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 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 anti-perthitic, and it contains a few biotite inclusions. Albite twins are common, Carlsbad twins less so, and pericline twins are rare. Plagioclase is altered in varying degree to sericite, mixtures of sericite

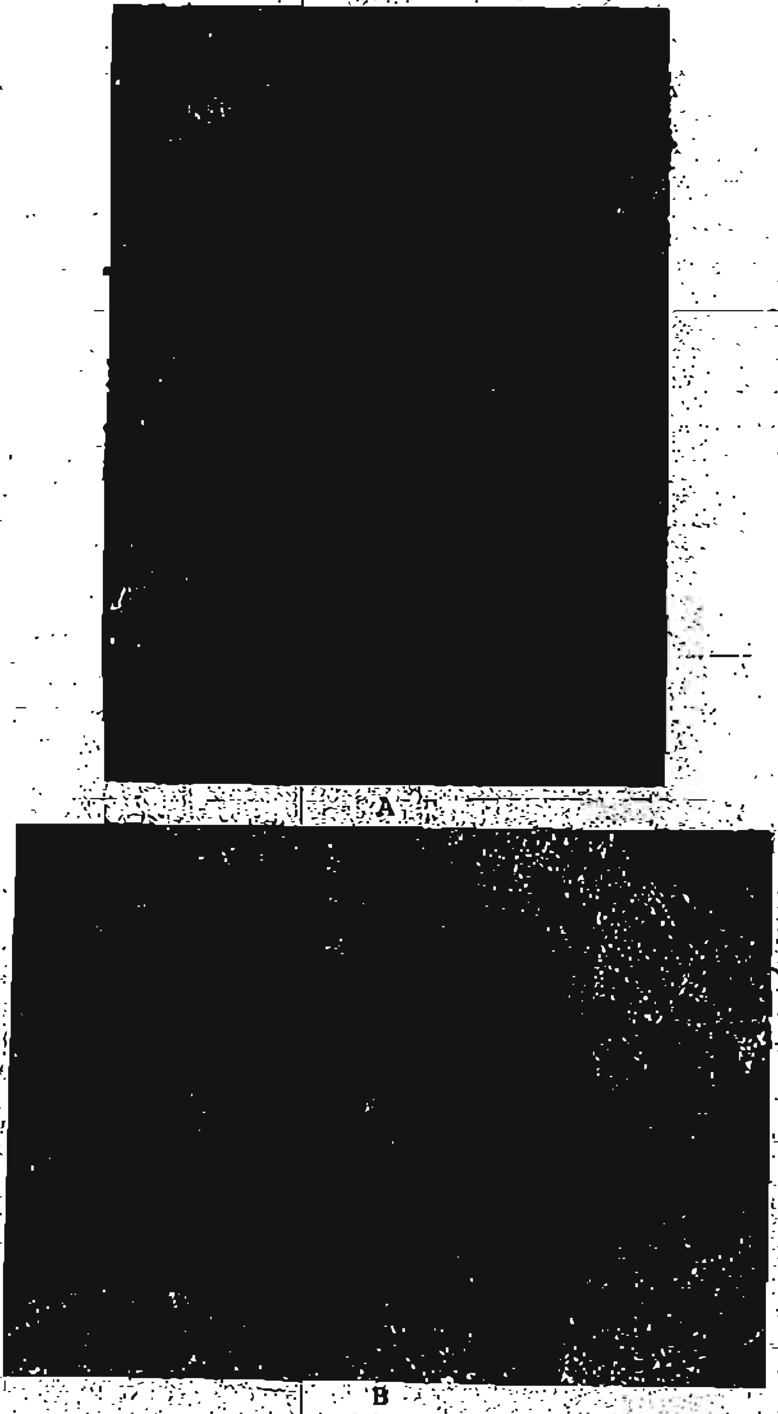

Figure 8. Alteration in porphyritic granite. Okpilak River.

A. Unaltered potash feldspar megacrysts in massive granite.

B. Flattened relict megacrysts composed of chlorite and sericite in schistose granite.

and calcite, and in "pink and green" granite is partially saussuritized with resulting sericite, chlorite, and epidote.

Quartz. Quartz occurs as large anhedral grains, in interstitial microcrystalline aggregates, as subhedral to euhedral megacrysts as much as one 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 which are large enough to observe this feature. Randomly distributed microlites including rutile are common in larger grains; in quartz which shows pronounced strain effects (fracturing, irregular wavy extinction, and anomalous 2V) trains of microlites are present. At least two or more generations of quartz are probably present in the granitic rocks; large anhedral quartz grains and quartz megacrysts are interpreted to be early; quartz veinlets in feldspars and aggregates of small grains 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_γ=1.657-1.662). It also exhibits pale green to light olive hues (n_γ=1.636-1.651), probably the result of alteration. Grains are mostly subhedral, commonly bent to shredded, and commonly enclose abundant aggregates of sphene, euhedral to subround zircon grains with halos in fresh biotite, euhedral apatite, and needle-like inclusions. Partial or complete alteration of biotite to chlorite or to muscovite and sericite is common. The muscovite contains relict inclusions of abundant whitish opaque material, probably leucoxene after granulated sphene, as coatings or along cleavage planes. Magnetite is commonly associated with altered biotite.

Muscovite also 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. Textures and mineral grain relationships contain features that might be variously interpreted as due either to melt crystallization or to metasomatism. The writer believes that most of the granite was derived from crystallization of a mobile body, although some granitic rocks along some margins of the pluton may represent granitized country rock.

Most of the feldspar relationships suggest that potash feldspar was late, and is in part a replacement of plagioclase. The evidence includes 1) optically continuous islands of albite-oligoclase in K-spar (fig. 9,A), 2) irregular embayments between K-spar and plagioclase in which plagioclase orientation corresponds with plagioclase islands in the K-spar grains, 3) "cores" of sericitized plagioclase entirely or nearly enclosed by K-spar megacrysts (fig. 9,C), 4) albite rims on plagioclase which in nearly all cases adjoin microcline, and imply a reaction other than simple late stage

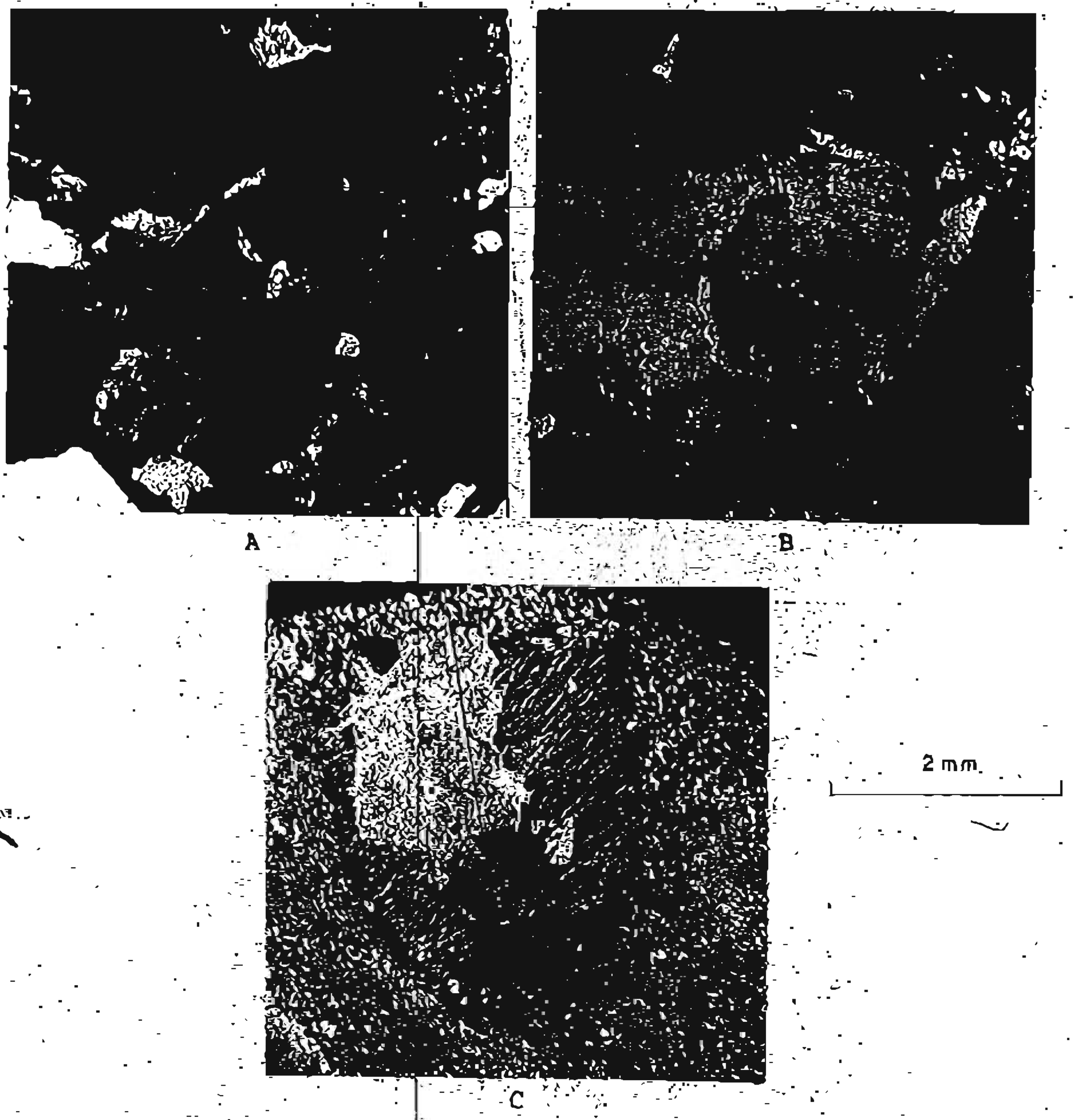

Figure 9. Photomicrographs of perthitic microcline and plagioclase intergrowths or replacements. Crossed polars.

A. Anhedral microcline grain (dark) with patchy optically oriented plagioclase and other plagioclase inclusions. Boulder Creek.

B. Plagioclase crystal partly enclosing patchy microcline (dark). Boulder Creek.

C. Euhedral perthitic microcline crystal nearly enclosing sericitized plagioclase in fine groundmass showing "flow" texture. Dark Creek.

unmixing, and 5) sieve structure in K-spar megacrysts, with fine-grained groundmass grains parallel to crystal boundaries (fig. 10,A,B). There are some exceptions to these relationships: 1) in some 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 K-spar, and 3) some plagioclase appears to have replaced K-spar (fig. 9,B). The latter relationship may be evidence of a late stage of albitization following crystallization of microcline.

From the evidence cited above, the writer concludes that the sequence of feldspar development, ascribed to melt-cryatallization, was as follows: the partially crystallized melt was represented by a one-plagioclase feldspar stage which, by melt reaction, was partly converted to K-spar with attendant albite-rim and perthite unmixing. Laboratory evidence does not preclude the possibility that two-feldspar granite may have resulted from an earlier one-feldspar stage (Tuttle and Bowen, 1958, p. 137). The few occurrences in which plagioclase appears to replace K-spar may indicate the onset of a second generation of plagioclase.

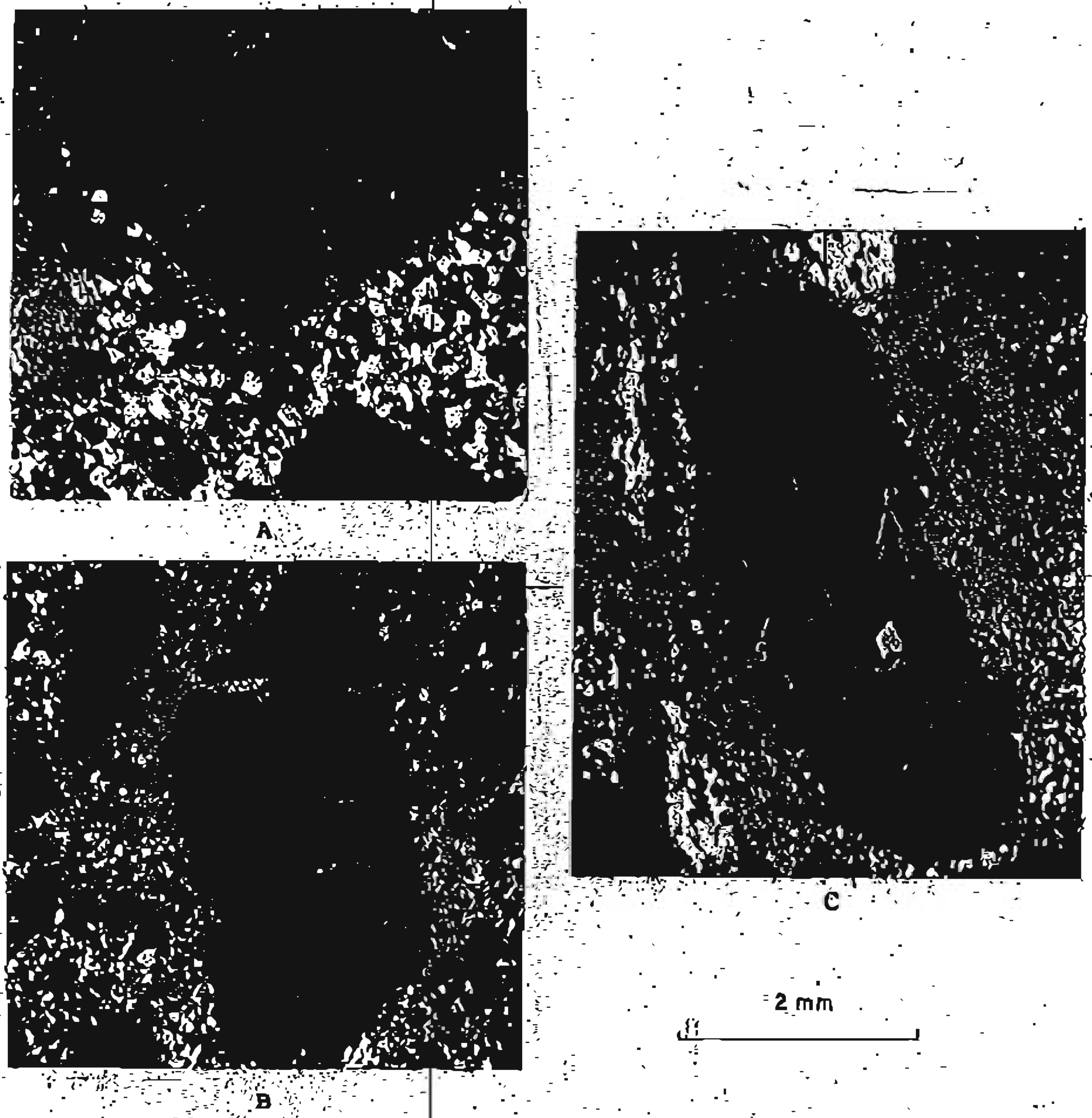

Figure 10. Photomicrographs of perthitic microcline megacrysts in Romanzof granite. Crossed polars.
A. Euhedral crystal showing marginal growth (M) into fine-grained dominantly quartz groundmass. Okpilak River, east fork.
B. Euhedral crystal with rounded corners possibly the result of granulation. Dark 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. Sweat Creek.

For the Romanzof granite, the sequence of crystallization is believed to have been as follows:

Oldest 1. Euhedral zircon, apatite, and magnetite

2. Plagioclase megacrysts, including cores of zoned crystals, and myrmekite. Biotite.

3. Potash 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 crystallization of potash feldspar; anhedral quartz grains and quartz veinlets in feldspars.

7. Partial replacement of microcline by albite?

8. Deuteric and hydrothermal mineral alterations and introductions, perhaps in part not related to granite emplacement. Tourmaline; chlorite, muscovite, sericite, and magnetite after biotite; sericite and epidote after plagioclase; vein-

Youngest and some groundmass-quartz; flourite; sulfides.

Although the above sequence implies melt crystallization, potash 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). Crystalloblastic aspect, sieve structures, and accompanying shredded biotite and seriate textures are common. Microcline megacrysts are present in inclusions within the granite and in Neruokpuk Formation quartzites short distances from the granite contact. The presence of granitized zones with dents de cheval in some marginal parts of the body is a distinct possibility.

Modal Composition

Results of modal analyses of 21 granitic rock samples from the Okpilak batholith are shown in table 8 and figure 11. The average mode of the 21 analyses is 36% perthitic microcline, 29% plagioclase, and 35% quartz. They indicate mostly quartz monzonite and a few granite compositions. Six samples show microcline and plagioclase percentages within 2 percent of one another. No distinct compositional trends within the pluton are evident from the samples examined. Although the modes exclude minor accessories and vein material, all other quartz was included. Some of the interstitial microaggregate material, dominantly quartz, may have been introduced after consolidation. The microcline megacrysts also may be later porphyroblasts, or replacements of earlier plagioclase phenocrysts by potash metasomatism or melt reaction. Estimated corrections for these possible factors would indicate that the pluton may have initially had a grandioritic composition.

Many of the modes and the average modal composition are generally in accord with the low-temperature trough in the system $NaAlSiO_4$-$KAlSiO_4$-SiO_2 of Bowen (from Turner and

Table 8. Modal analyses of granitic rocks from Okpilak batholith, Romanzof Mountains, Alaska.

Field Sample No.	Micro-cline	Plagio-clase	Quartz (includes micro-quartz)	Bio-tite *	Tour-maline	Micro-Quartz (included in Quartz)	Classification	Granite Textural Facies
57ASa35	51.3	26.0	15.6	7.0		+	Granite	Variable
57ASa67	48.3	18.9	16.0	5.1		+	Granite	Coarse
~~57ASa75~~	~~46.8~~	~~28.4~~	~~23.3~~	~~1.4~~			Quartz monzonite	Variable
57ASa74	44.6	27.4	26.2	1.8			Quartz monzonite	Variable
58ASa60	42.7	17.8	31.9	7.6			Quartz monzonite	Coarse
58ASa182(1)	39.1	22.4	33.5	5.0		21.0	Quartz monzonite	Coarse
57ASa73	37.7	27.6	32.2	2.5			Quartz monzonite	Variable
58ASa68	35.2	26.2	34.5	2.8			Quartz monzonite	Variable
58ASa40	33.8	27.4	33.0	5.8			Quartz monzonite	Variable
58ASa19	33.6	28.0	29.1	7.8		+	Quartz monzonite	Porphyritic
58ASa65	32.2	31.5	32.4	2.9	0.2		Quartz monzonite	Variable
57ASa146	29.9	27.9	36.9	5.4		2.1	Quartz monzonite	Variable
58ASa35	29.7	24.4	37.6	5.8		24.1	Quartz monzonite	Variable ?
57ASa70	27.1	32.2	34.6	6.0	+		Quartz monzonite	Variable
58ASa182(2)	25.9	25.4	36.9	7.8	+	24.5	Quartz monzonite	Coarse
57ASa89	26.0	24.0	45.8	4.1			Quartz monzonite	Porphyritic
57ASa300	25.9	24.4	42.1	7.6		+	Quartz monzonite	Coarse
57ASa23(1)	24.5	32.9	34.5	8.2			Quartz monzonite	Porphyritic
57ASa141	23.9	36.6	31.8	7.8		11.6	Quartz monzonite	Porphyritic
58ASa111	23.5	23.5	47.1	5.9			Quartz monzonite	Variable
57ASa75	19.1	26.5	38.8	-	15.2		Quartz monzonite	Variable

* Includes alteration products and inclusions.

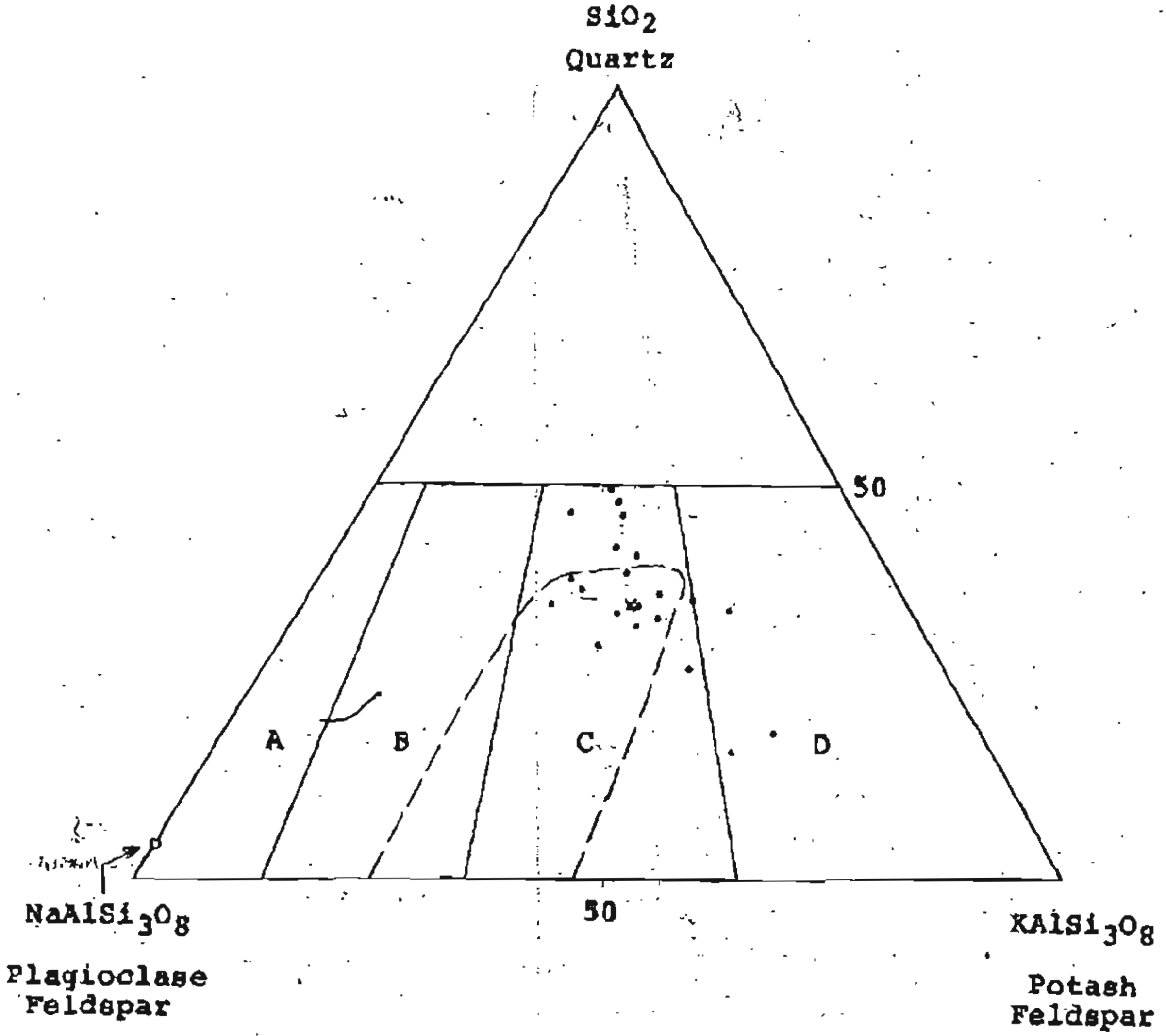

Figure 11. Composition distribution diagram of leucocratic constituents in 21 modal analyses of granitic rocks from Okpilak batholith. (Points indicate modal analyses; x indicates their average. Solid lines in lower half of diagram enclose fields of A, tonalite; B, granodiorite; C, quartz monzonite; D, granite; highly felsic rocks not included. Dashed line encloses Bowen's low-temperature trough of system $NaAlSiO_4$-$KAlSiO_4$-SiO_2)

Verhoogen, 1951, p. 148), indicating crystallization from a melt (fig. 11). Others indicate a higher quartz content, and a few show excessive potash feldspar. The latter may be the result of locally abnormal concentration of microcline in sampled localities.

Chemical Composition

Six rapid rock chemical analyses (Shapiro and Brannock, 1956) are given in table 9. All of the samples except Sample 58ASa61 were relatively unaltered granitic rocks selected after examination of thin sections. 58ASa61 is a bleached and pyritized granite selected for comparison with the adjoining unaltered sample 58ASa60, and is discussed on page 206. The average of constituents of all samples except 61 is also shown. The greatest variations are those of FeO, CaO, Na_2O and K_2O, and TiO_2, explained respectively by variations in amount and probable composition of biotite; variations in amount of calcite, sphene, and minor epidote; relative amounts of potash feldspar and plagioclase; and relative abundance of sphene and possible titanium in biotite.

Textural Facies

Although there appears to be little mineralogical variation in the Romanzof granite, 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, include a locally developed marginal porphyritic granite facies characterized by abundant

Table 9. Rapid rock chemical analyses of granitic rocks from Okpilak batholith, Romanzof Mountains, Alaska.

Analyses (weight percent)							
Field No.	58ASa60	58ASa61**	57ASa65	57ASa70	58ASa182	57ASa142	Average (excluding 58ASa61)
Lab. No.	156460	156461	156462	156463	156464	156465	
Textural Facies	Coarse	Coarse	Variable	Variable	Coarse	Porphyritic(?)	
SiO_2	73.2	78.3	76.5	76.0	75.5	74.7	75.2
Al_2O_3	13.5	11.2	12.1	13.1	11.8	12.8	12.6
Fe_2O_3	.8	.2	.6	.9	.6	1.0	.8
FeO	1.1	.05	.76	.22	1.6	.73	.88
MgO	.54	.27	.22	.15	.31	.35	.31
CaO	.53	.26	.91	.40	1.1	1.3	.85
Na_2O	2.7	5.4	2.5	3.3	2.4	2.6	2.7
K_2O	5.9	.70	5.0	4.6	4.9	4.8	5.0
H_2O	.86	.57	.76	.72	.73	.72	.76
TiO_2	.24	.33	.16	.04	.24	.21	.18
P_2O_5	.07	.02	.03	.01	.07	.06	.05
MnO	.04	.02	.03	.04	.06	.04	.04
CO_2	.13	.05	.05	.13	.05	.05	.08
FeS_2*	.08	2.0					
Total	100.	99.	100.	100.	99.	99.	
Specific Gravity	2.59	2.67	2.64	2.64	2.68	2.69	

* Total sulfur calculated to FeS_2

** Altered granite

Analysts: P. L. D. Elmore
S. D. Botts
I. R. Barlow
G. Chloe

large microcline megacrysts; a middle to marginal variable facies of fine- to coarse-grained granite exhibiting alternations in grain size; and an inner to marginal 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 6000 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 portion of the Jago stock. Aplite dikes and inclusions of country rock are relatively common in this facies. The microcline megacrysts, as much as 3 inches in maximum dimension, constitute an estimated 10 to 30% of the rock. They are euhedral-tabular to sub-spheroidal; most of them are tabular with well rounded edges. Some enclose biotite flakes and some are fringed by concentrations of biotite. Their microscopic features have been described on pages 114-115. 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 Romanzof 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 imperceptibly 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, as well as deuteric or later minerals. However, whether these features are in reality more limited to the variable facies, or were simply 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 dimensions, and are commonly euhedral. The author feels that interpretation of primary granite structures in the variable facies is on firmer ground than in 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 eastern and western margins where the contact rocks clearly show intrusive effects and contact metamorphism.

Coarse facies granite may comprise several areas in the interior of the Okpilak batholith as well as the central portion of the Jago stock. The granite is dominantly coarse- to very coarse-grained. In some parts of the area, as McCall Glacier, it lacks discernible linear or planar directional elements; in others it is gneissoid, gneissic, and cataclastic. The areas in the Okpilak batholith which appear to consist of this facies, shown on plate 1, include the area 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 Dark Creek, sharp irregular contacts between fine- and coarse-grained granite were locally observed. These may represent cross-cutting relationships near the facies boundary. Field photographs of the textural variations in the three facies are shown in figure 12.

Some dark schistose rocks with quartz and microcline megacrysts occur within the porphyritic facies, and may represent altered graphitic metasediments. The variable facies also includes some belts of quartz-muscovite schist, as along Leffingwell Glacier. Contacts between these rocks and granite are obscure; some are interfingering, and others seem to be gradational. Textural gradations in the variable

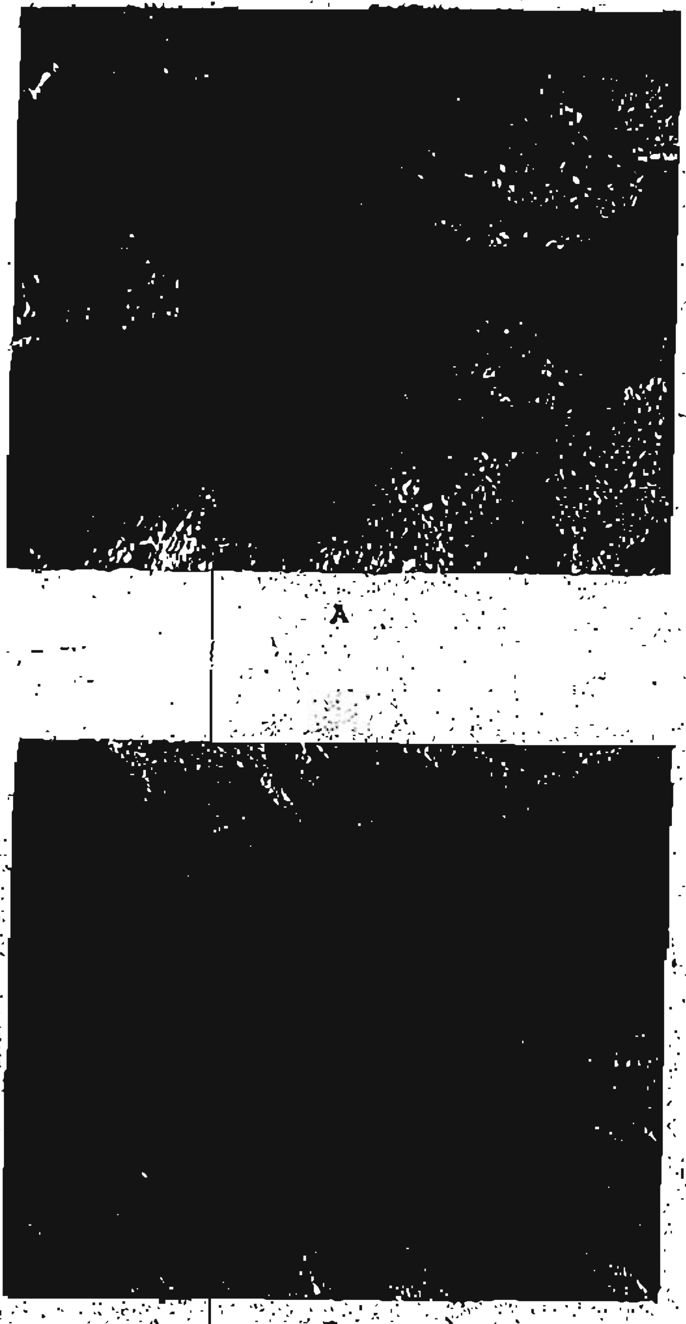

Figure 12. Textural facies in Romanzof granite.
A. Porphyritic facies granite, showing lineation of microcline megacrysts. Biotite foliation (not visible) dips towards observer. Leffingwell Creek.
B. Variable facies granite, showing mineralogical banding. East side Okpilak River.

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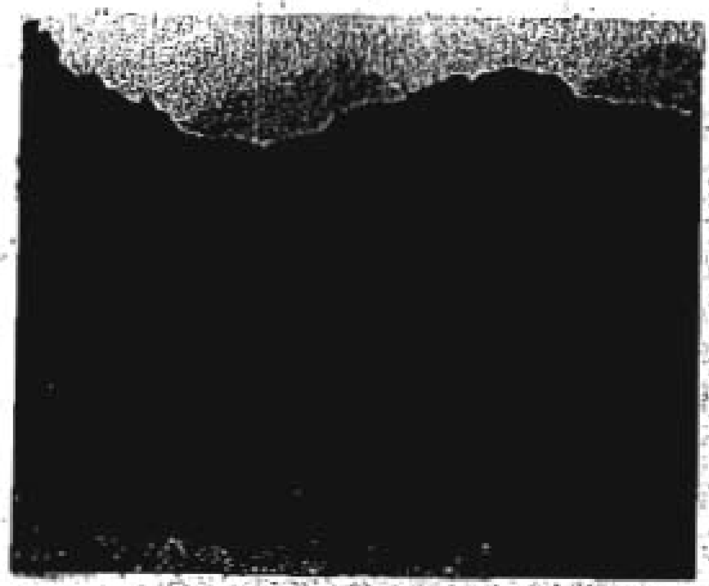


C

D

Figure 12 (cont.). Textural facies in Romanzof granite.
C. Coarse facies granite lacking in foliation. McCall Glacier cirque.
D. Coarse facies "gneissoid" granite; feldspar foliation trends from upper left to lower right. Okpilak River, near forks.

facies are interpreted to represent flow structure, but may be segregation banding or relict structures of granitized rocks.

The author interprets the porphyritic facies to represent an early, more fluid phase of melt influx with resulting large phenocrysts, succeeded by the variable facies, a congealing shell in which there was considerable variation of volatiles and stress-temperature conditions. An alternate interpretation is that the porphyritic facies in part represents a granitized paragneiss, grading into the variable facies, a zone of mixed rocks in which melting and crystalline flow was dominant. 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 essentially solid outer shells.

Granite-Country Rock Relationships

On a large scale, marginal contacts and general trend of the Romanzof granite 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 eastern margin of the Okpilak batholith, however, truncates units of the Neruokpuk Formation west of the Jago River (pl. 1; fig. 14), and the western margin is at least locally cross-cutting. The granite does not commonly exhibit definite chilled border zones, although fine-grained granite occurs along some contacts. Foliation and lineation of

Figure 13. Oblique view of west fork of Okpilak River looking southwest. Concordant contact between Romanzof granite (rg) and Neruokpuk Formation (nk) in foreground. Schistosity and bedding in the metasedimentary rocks dip south for many miles. Toe of Okpilak Glacier at left side. Photo by U. S. Navy.

Figure 14. Oblique view of west fork of Okpilak River, looking southeast. Contact between Romanzof granite (rg) phyllites, slates, and quartzites (nkpq) and quartzites (nkq) of Neruokpuk Formation. Contact interpreted to be intrusive, but quartzites may be faulted against underlying rocks. Photo by U. S. Navy.

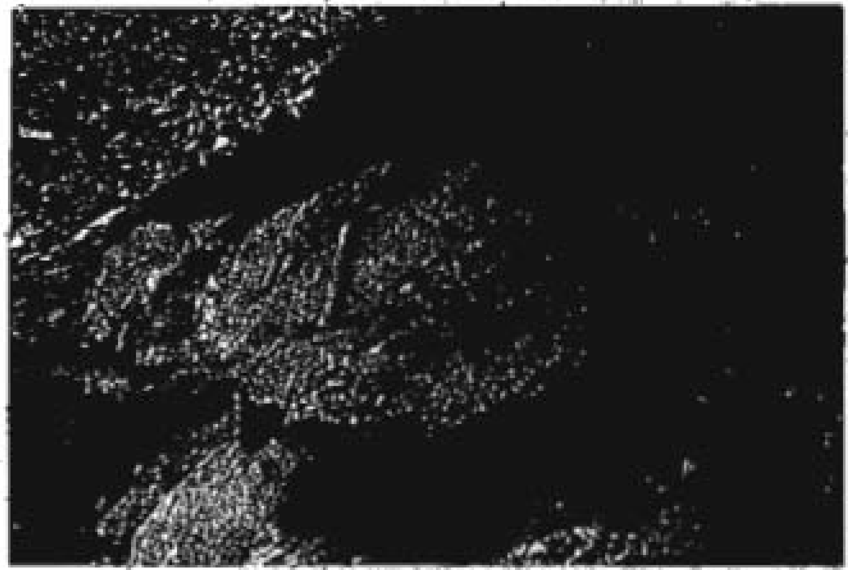
granite constituents along contacts with Neruokpuk Formation are generally parallel or subparallel to the contact trends. Near contacts with post-Neruokpuk units, features which are interpreted to be primary exhibit a rough parallelism to the contacts in some vicinities; in others they are at wide divergence to the contact trends.

In detail, two markedly different types of contacts characterize the margin of the granite: sharp concordant to cross-cutting contacts with or without contact metamorphic aureoles, and gradational contact zones in which porphyritic facies granite grades into schistose country rock. The first type of contact is restricted to areas in which the granite adjoins rocks of the Neruokpuk Formation; the second type to areas of the adjoining Kekiktuk Conglomerate and possibly Neruokpuk Formation clastic rocks along the northeastern margin of the batholith.

Abrupt contacts with the Neruokpuk Formation include:

1. Concordant and discordant tongue-like 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. 15,A).

2. Irregular granite apophyses in which angular broken and displaced inclusions of quartzitic country rock are imbedded. 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. 15,B).



A

B

Figure 15. Intrusive contact relationships of Romanzof granite with Neruökpuk Formation rocks.
A. Concordant and discordant contacts. West wall of Esetuk Glacier.
B. Fragmentation of quartzite by infiltration of granite. Boulder, Dark Creek.
(continued on next page)

C

Figure 15 (cont.). Intrusive contact relationships of Romanzof granite with Neruokpuk Formation rocks.
C. Infiltration of granite along fractures in quartzite. Boulder, Dark Creek.

3. Smaller scale infiltration of granite along fractures in quartzites with little displacement of country rock (fig. 15,C).

4. Concordant planar to gently curving contacts which can be traced for at least several hundred 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 undisturbed 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 penetration of granite into minute fractures. Structural elements within the granite (p. 145-156) and regional structural relationships are interpreted to represent forceful injection as the dominant emplacement mechanism.

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

Calc-silicate rocks and hornfels are locally well developed along the west and east sides of the Okpilak batholith; several hundred feet overlie the granite along Boulder Creek in the Jago River drainage, and along the south side of Esetuk Glacier in the Hulahula River drainage. In outcrop they are mostly aphanitic, dense, dark, weather greenish gray, and are highly ironstained, with some mineralogical banding. Along the Jago River, rocks include epidote-amphibolites in which tremolite-actinolite, cordierite, and epidote are dominant minerals with lesser amounts of accessory 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 (40%), albite (40%), biotite (10%), quartz (10%), and microcline (10%), with abundant accessory sphene and apatite, pyrite, magnetite-ilmenite, and tourmaline. Chlorite and sericite are the chief alteration products. The contact rocks along the Jago River belong to the albite-epidote hornfels facies (Fyfe, Turner, and Verhoogen, 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 and 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 hornblende hornfels facies (Fyfe, Turner, and Verhoogen, 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. A traverse upwards from the lowest granite contact crossed:

1. Coarse-grained, in part tourmalinized granite 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 feet across and 5 feet high invade country rock (fig. 15,A). The contact is sharp; granite within 1 foot of contact contains calcite. The hornfels, dark greenish-gray, in part banded, contains tremolite-actinolite (40%), epidote (30%), clinozoisite(?) (20%), and quartz (10%).

2. 6 feet to 40 feet above contact. Aphanitic, greenish-gray to rose colored hornfels, includes bands of red garnet as much as 1 inch thick. In thin section the bands are about 70% grossularite (n=1.765±.003) in part with anomolous birefringence enclosing crystals of hedenbergite, and fine-grained groundmass composed of quartz, cordierite(?), calcite, and chlorite, with calcite-quartz veinlets. This unit also includes phyllite and gnarled reddish, greenish, and grayish calcareous rock.

3. Estimated 40 to 80 feet. Mostly rubble of epidote-amphibolite like that in unit 1 with grossularite concentrated in bands, sphene in chloritic bands, and lesser amounts of greenish stained rock containing massive, dull gray, very fine-grained magnetite.

4. 80 to 87 feet. Massive, banded, olive green to dark green, aphanitic rock; dense, hard, with gnarled banding and gunmetal blue stain.

5. 87 to 98 feet. Platy dark gray, limestone, 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 yellowish opaque material.

6. 98 to 143 feet. Reddish and greenish gunmetal blue-stained aphanitic rock. Some greenish and bluish bloom (copper carbonates?). An epidote-amphibolite showing much cross-shearing indicating 2 directions and stages of disturbance.

7. 143 to 163 feet. Covered.

8. 163 to 168 feet. Green chloritic schist.

9. Granite rubble. Granite truncates country rock above this, which is hedenbergite-grossularite-quartz-cordierite rock with abundant accessory sphene and pyrite, and shows shearing effects similar to those mentioned above.

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, Turner, and Verhoogen, 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 intensities away from the granite.

The gradational contact zone between porphyritic granite and overlying quartzites of the Kekiktuk Conglomerate differs from the contact rocks described above. It is well exposed along the northern limit of the granite along the Okpilak River and along the east wall of the Jago River valley. In these areas, about 50 to 130 feet of quartz-sericite-chlorite schistose rocks, including 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. A traverse across this zone along the Okpilak River, augmented by thin section study, reveals:

1. Granite, fine- to very fine-grained, ironstained, 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. 0 to 20 feet. Rubble of aplitic rock, light gray, partly ironstained, consisting of aligned intergrown mass of quartz, plagioclase, microcline, and rare biotite.

3. 20 to 40 feet. Schistose granite(?), dark greenish gray, with relatively fresh to altered microcline megacrysts as much as 2 inches in length, and quartz megacrysts as much as 1/2 inch in diameter. Thin sections of these rocks show 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.

4. 40 to 45 feet. Grayish-green schist 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.

5. 45 to 55 feet. Schist like that in unit 3.

6. 55 to 95 feet. 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 inch diameter, with more abundant subround to subangular grains of quartz. Strong metamorphic "flow" texture of groundmass around grains.

7. 95 to 105 feet. 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 that in biotite of granite, and quartz grains.

8. 105 to 155 feet, estimated. Covered to Lisburne Group limestone.

Although a specific granite-metasedimentary contact might be picked between units 2 and 3 of the above section, the contact is more vague in other localities. Along the Jago River, schistose "granite" containing microcline megacrysts appears to vary from 20 to 75 feet in thickness, and is overlain by 20 to 30 feet of transitional schistose rock without recognizable feldspar, which grades upward into 50 to 200 feet of less schistose quartzite.

The nature of the abrupt contacts establishes the granite as post-Neruokpuk Formation in age. Proper interpretation of the schistose gradational contacts with the Kekiktuk Conglomerate is important in ascribing an upper age limit to the granite (p. 170). The inclusion-filled mica and chlorite in Kekiktuk rocks suggests former biotite like that in the granite. The granite is not known to intrude or alter post-Kekiktuk rocks. The differences between the distinct contact metamorphic and the transitional schistose contact zones, providing the latter were truly associated with granite emplacement, appear to relate to the compositional differences of the wall rocks, and to the granite textural facies adjoining them. Most of the definite contact metamorphic rocks adjoin the variable-textured facies, and most transitional contact rocks adjoin porphyritic facies granite. High viscosity and low temperature of a porphyritic facies melt during its final emplacement might explain the scarcity of pyrometasomatic rocks at these contacts.

Structural Elements in Granitic Rocks

The Okpilak batholith and the Jago stock are parts of the same pluton separated on outcrop by a complex overturned synclinal infold. The granitic bodies appear to be synorogenic in that their gross trends and older structural features generally parallel those of enclosing Neruokpuk Formation rocks. However, post-emplacement deformation may have resulted in structural shortening which makes the above classification more apparent than real. If present strain features represent later deformation, then the pluton may originally have been elongate along a more easterly trend.

The following planar and linear directional elements in the Romanzof granite range from well-developed to absent. Although they are listed in a general chronological sequence of development, some features overlap, and the positioning of others is uncertain.

1. Zones of alternating fine- to coarse-grained granite (rare to common)
2. Bands of alternating light and dark (biotite-rich) granite (rare)
3. Elongate inclusions of quartzitic to schistose rock (rare)
4. Zones of migmatite or lit-par-lit rock (very rare)
5. Zones of metasedimentary(?) schistose rock (rare)
6. Foliation of biotite <u>and</u> feldspars (gneissoid granite) (common to rare)
7. Foliation and lineation of feldspars, chiefly microcline (common to rare)

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 and sheared zones with or without associated zones of sulfide enrichment and silicification (common)
19. Joints and fractures (abundant)

During analysis of directional elements in the granite, field readings of their trend and inclination and possibly related linears seen on aerial photographs were plotted on separate transparent sheets and compared. For some directional elements such as joints and biotite foliation, this method was successful in broad areas; for others, such as textural differences and feldspar foliation, the results are inconclusive. Recorded joints were analyzed using a Schmidt equal-area net (pl. 4). Attempts to relate different joint sets to foliation in isolated localities by stereographic projection methods were made, but results were erratic, and this method was abandoned.

Primary features and features of uncertain derivation

Directional elements within the pluton which are considered by the writer to be most likely primary are:

1. Alignment of two or more similar inclusions
2. Textural banding
3. Compositional banding of biotite-rich and leucocratic granite
4. Parallel foliation of both biotite and feldspar in relatively undeformed granite.

The first three features are not as abundant as other directional elements in the granite. Trends and attitudes of the above features are shown in plate 5.

In some parts of the pluton, especially in marginal portions, several puzzling planar and linear elements involving primary features and foliation of uncertain significance can be seen in the same outcrop. In granite gneiss outcropping in the cirque wall of a hanging glacier tributary to Leffingwell Glacier, parallel feldspar and biotite foliation, strike N.70°E. and dip 57°SE. with lineation of 90°, are crossed by biotite schlieren at E.-W., 60°S. Along Esetuk Glacier, feldspar foliation is at N.85°W., 80°SW. with lineation 60°-70°SW, and a cross-texture of faint biotite schlieren and some feldspars at N.85°E., 45°SE. Along the lower part of Leffingwell Creek, biotite foliation is N.85°E., 70°SE. and many microcline megacrysts are oriented parallel to or normal to this direction. Bands of concentrated microcline megacrysts with their long axis parallel to biotite foliation are, however, at N.85°W., 60°NE. Are the primary layers north-dipping with later reorientation by stresses which influenced the biotite alignment? A nearby locality along Leffingwell Creek shows biotite foliation of N.60°E., 80°-85 NW., subparallel feldspar at N.55°E., 50°-80°NW. with a suggestion of 70°W lineation, both crossing textural banding having an attitude of N.60°W., 35°NE. Here it would also appear that primary layers do not coincide well with foliation directions.

As a result of the confusing relationships described above, the deformational effects in the pluton, and the possibility that microcline megacrysts are porphyroblasts only locally parallel to primary features, the writer is in considerable doubt about the meaning and significance of foliation. The granite exhibits features which could be interpreted as originating either in a liquid or solid state, or in an intermediate "mushy" medium. Each part of the area was examined with these possibilities in mind, and interpretations were made on the basis of texture. Feldspar foliation, and combined feldspar-biotite foliation, in relatively undeformed granite are interpreted to represent either primary structure (flow layers?) or orientation by stresses directed normal to the above foliations during emplacement of the enclosing granite. Biotite foliation, discussed below, is interpreted to be mostly secondary. Textures and structures which are interpreted to reflect primary features, a combination of primary and secondary features, and deformation of solid granite, are respectively illustrated in figure 12, A,B,C, and D; figure 16, and figure 17, A and B.

Foliation of feldspar and biotite

Foliation of feldspar and biotite ranges from well developed to indistinguishable. In many parts of the area, feldspar foliation generally coincides with trends of primary features. Biotite foliation is normally very well developed (fig. 18), in some places coincides with feldspar foliation, but commonly its strike lies at acute or even right angles to the feldspars; it bears similar relationships to primary features. In other localities biotite and feldspar coincide or are subparallel and are reflected by well-developed fractures. In many places, however, streaking of minerals, thin schlieren, fine-grained granulated quartz, and a high degree of fracturing and augen texture of feldspars indicate probable realignment by dynamic metamorphism after consolidation. Extensive alteration of biotite to chlorite may indicate retrograde metamorphism accompanying this deformation.

Feldspar foliation (pl. 6) is mostly steeply-dipping to vertical, and the dominant dip component of foliation and lineation appears to be southerly, although northerly dips are probably dominant in the southeastern and southern portions of the Okpilak batholith. Analysis of feldspar foliation indicates that it more closely coincides with wall rock contacts and with the few recognizable primary features than does biotite foliation. The lack of foliation readings in

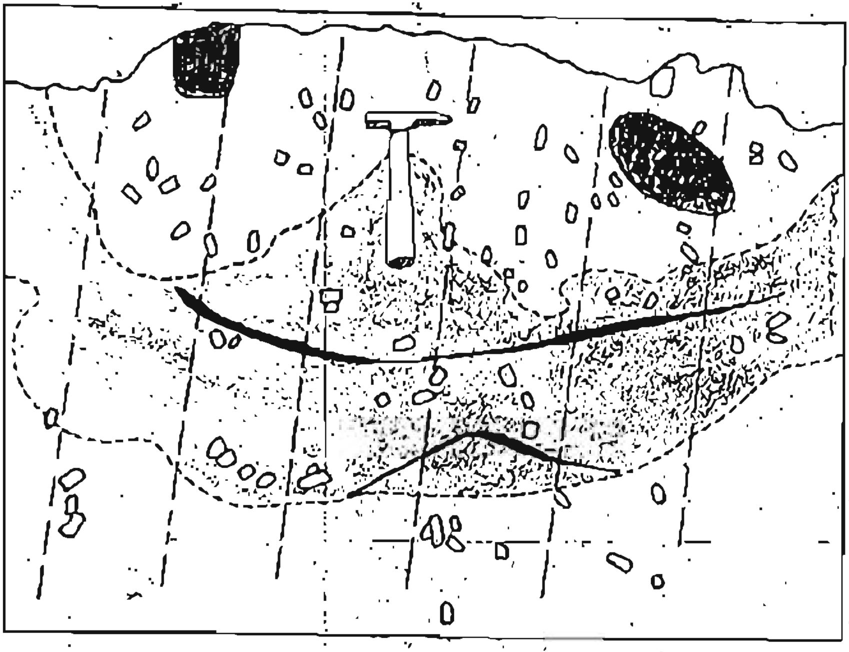


Figure 16. Drawing showing relationships of primary and secondary features in granite, Okpilak River, Alaska. Dark bodies in upper part are inclusions; dark broad band in center is biotite-rich granite; black thin bands are schlieren. Small rectangles and ellipses are microcline megacrysts; steeply-dipping dashed lines represent biotite foliation, the strike of which is roughly normal to paper. From photograph.

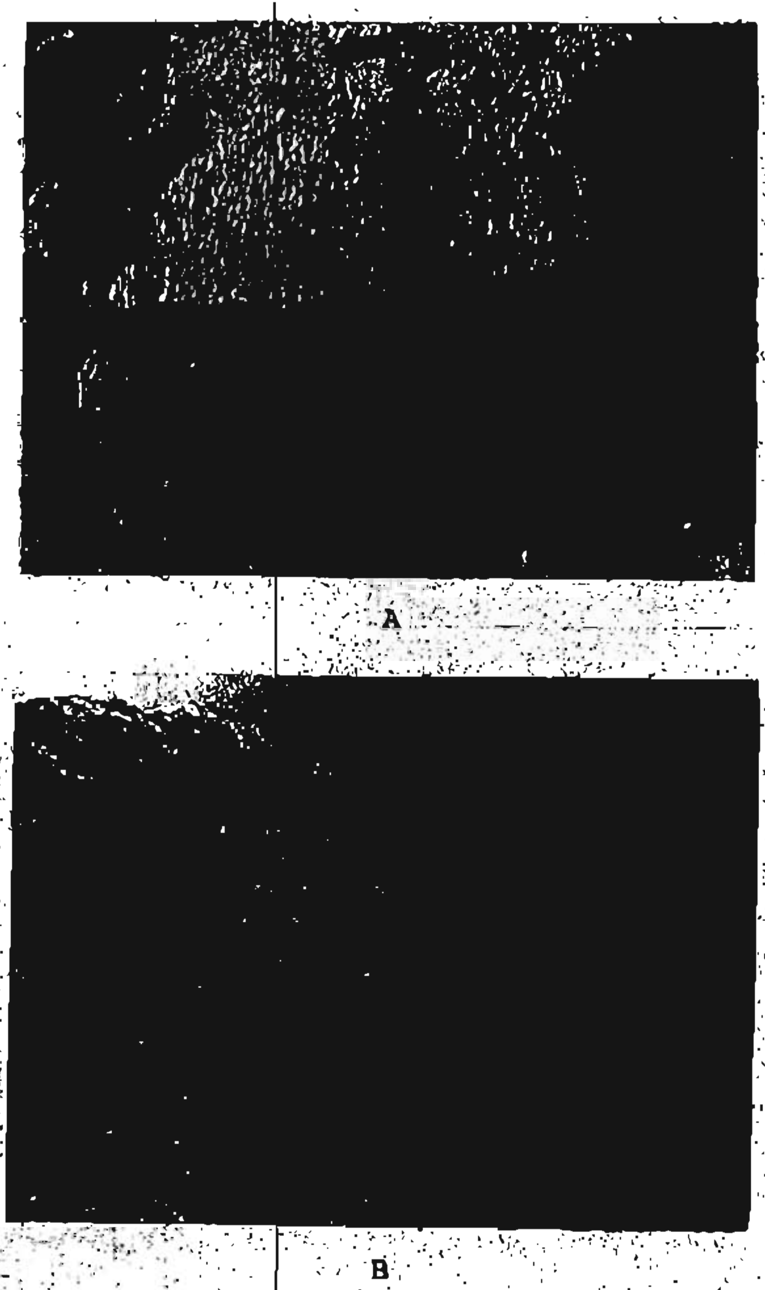


Figure 17. Romanzof granite showing strong secondary foliation. Okpilak River.
A. Gneissic granite.
B. Schistose granite with fractured microcline megacrysts.

Figure 18. Oblique view of Okpilak-River valley, looking east. South-dipping fracture pattern on mountainside reflects well-developed biotite foliation and schistosity cut by north-trending shear zones and joints. North-trending fault in background dips steeply towards observer. rg, Romanzof granite; MI-Mk, Lisburne Group and Kekiktuk-Kayak(?) unit; Ps, Sadlerochit Formation; s, shear zone. Fourth advance lateral moraines at base of mountain. Photo by U. S. Navy.

some of the area covered by field work indicates areas of schistose and gneissic granite or, in the McCall Glacier vicinity and east, areas where foliation was not recognized.

Biotite foliation is shown on plate 7. In the northern part of the Okpilak batholith it strikes east-northeast and dips south. Farther south, attitudes and trends are more variable, but a dominant southerly dip component is strongly suggested. Dips range from moderate to steep. As an indication of primary structural features in the granite, biotite foliation is suspect for the following reasons: it closely coincides with schistosity and gneissic foliation in deformed granite, crosses some aplite dikes, parallels orientations of individual inclusions but not rows of inclusions, and parallels slaty cleavage in the sedimentary rocks north of the batholith which are thought to be younger than the granite (p. 174). Biotite foliation may nevertheless be a feature reflecting stresses in a nearly or wholly consolidated outer shell of the pluton during the late stages of emplacement; if so, the granite would post-date the Jurassic rocks of the area. Biotite foliation, then, could have provided a preferred directional control for later cataclastic effects and schistosity.

Schistosity and schistose zones

Features ascribed to post-consolidation deformation within the granite which may or may not be related to granite emplacement, but which appear to be interrelated, include schistosity, linear schistose zones and gneissic foliation, some joints, all shown in plate 4, faults, and possibly biotite foliation, already discussed.

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 well expressed, and here biotite and feldspar foliation are locally but not everywhere 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 diverse trends suggest that this part of the area has been subject to two or more directions of shearing stress.

Zones of sheared, schistose granite from a few feet to tens of feet wide are common in some portions of the area (fig. 19). In these, granitic constituents have been broken, rotated and in part recrystallized to chloritic and sericitic schistose granitic rock. Their attitudes, shown on plate 4, are generally at variance to those of the schistosity and gneissic structure described above. Many of these zones strike northerly and lead one to suspect that they are related to the north-striking pattern of prominent joints and faults observed north of the granite. Relationships of these zones

Figure 19. Sheared schistose zones in Romanzof granite on east wall, Okpilak River valley. Resistant pinnacles of relatively unaltered granite alternate with swales of schistose granite. Looking south.

to the schistosity and gneissic foliation described above is obscure; schistosity in most of the zones parallels their attitudes. In some vicinities, however, schistosity crosses zones of schistose granite. An example is a N.30°W. striking zone near the northern front of the granite in the Okpilak valley, where schistosity in the zone and biotite foliation in the adjacent granite is N.80°E. Mineralogy of 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 in the example above, and the fact that some zones are subparallel to primary features, suggest that some of the zones closely followed granite emplacement, and that they represent planes of weakness which controlled later dislocations.

The shear effects probably occurred at considerable depth with the result that the original granite constituents were partially to wholly altered by reconstitution, addition of volatiles (mostly water) and addition of Fe and Mg. Biotite and feldspars were altered to mixtures of chlorite and sericite; microcline megacrysts were converted to flattened relicts of sericite-chlorite (fig. 8,B); quartz was granulated and in part recrystallized to quartz metacrysts.

Dikes

Pegmatite and aplite

Pegmatites are relatively rare in the Romanzof granite and are of simple composition: feldspar (70%), quartz (25%), locally biotite or chlorite (5%), and accessory tourmaline and fluorite as small aggregates. Few pegmatites exhibiting sharp cross-cutting relationships were seen; most of them show irregular gradational relationships with adjoining granite. A few small "pods" of pegmatite several feet wide were seen in granite, but they are not miarolitic. No foliation was noted in pegmatites, and no relationships with schistose zones were seen in the exposures examined. Distribution of pegmatites relative to granite facies is not known.

Aplite dikes are relatively common, and may be most abundant in the variable and porphyritic facies of the granite. They cross-cut all essential granite minerals including feldspar megacrysts, and inclusions. They are commonly planar but are locally curved and appear to be folded. Their mineralogy corresponds to that in the adjoining granite, and some contain tourmaline, pyrite, and fluorite. Although the dikes are cross-cutting, biotite foliation where recognizable 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.

Locations and trends of aplite and pegmatite are shown on plate 5. 72 attitude readings on aplite dikes indicate that most dips are steeper 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 pluton also locally correspond to trends of feldspar foliation and primary features and might be interpreted to represent longitudinal joints (Balk, 1937, p. 34-36). Some aplites might be interpreted to have filled cross joints and release fractures.

Quartz monzonite dikes

Two different compositional varieties of dark rocks in steeply-dipping tabular bodies were recognized in the Okpilak batholith. Both occur in the variable and coarse facies and possibly in the porphyritic facies, but their interrelationships are not known. They include dark gray porphyritic quartz monzonites, and green aphanitic mafic rocks. The mafic dikes are definitely intrusive, and are discussed along with mafic volcanic(?) rocks on pages 177-179. All contacts observed between the quartz monzonites and granite are sheared.

The quartz monzonites were seen in a single belt of northeast-striking dikes between Okpilak River and McCall Glacier. They dip steeply northwest and are as much as 300 feet thick. 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 tentatively inferred that they represent quartz-monzonite or mafic bodies. However, they may represent either schistose granite, included metasedimentary rock, or fine-grained granite with abundant dark lichen cover.

The quartz monzonites are characterized by abundant euhedral to ovoid perthitic microcline megacrysts which contrast strongly with the dark gray aphanitic groundmass. The megacrysts commonly show a strong preferred orientation parallel to the steeply-dipping dike sides, but are randomly oriented in some exposures (fig. 20). 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 constitutes the groundmass, with quartz 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 interpreted to represent primary structure roughly parallel those in the enclosing granite. The dark quartz monzonites are considered to be essentially cogenetic with the main mass of granitic rocks.

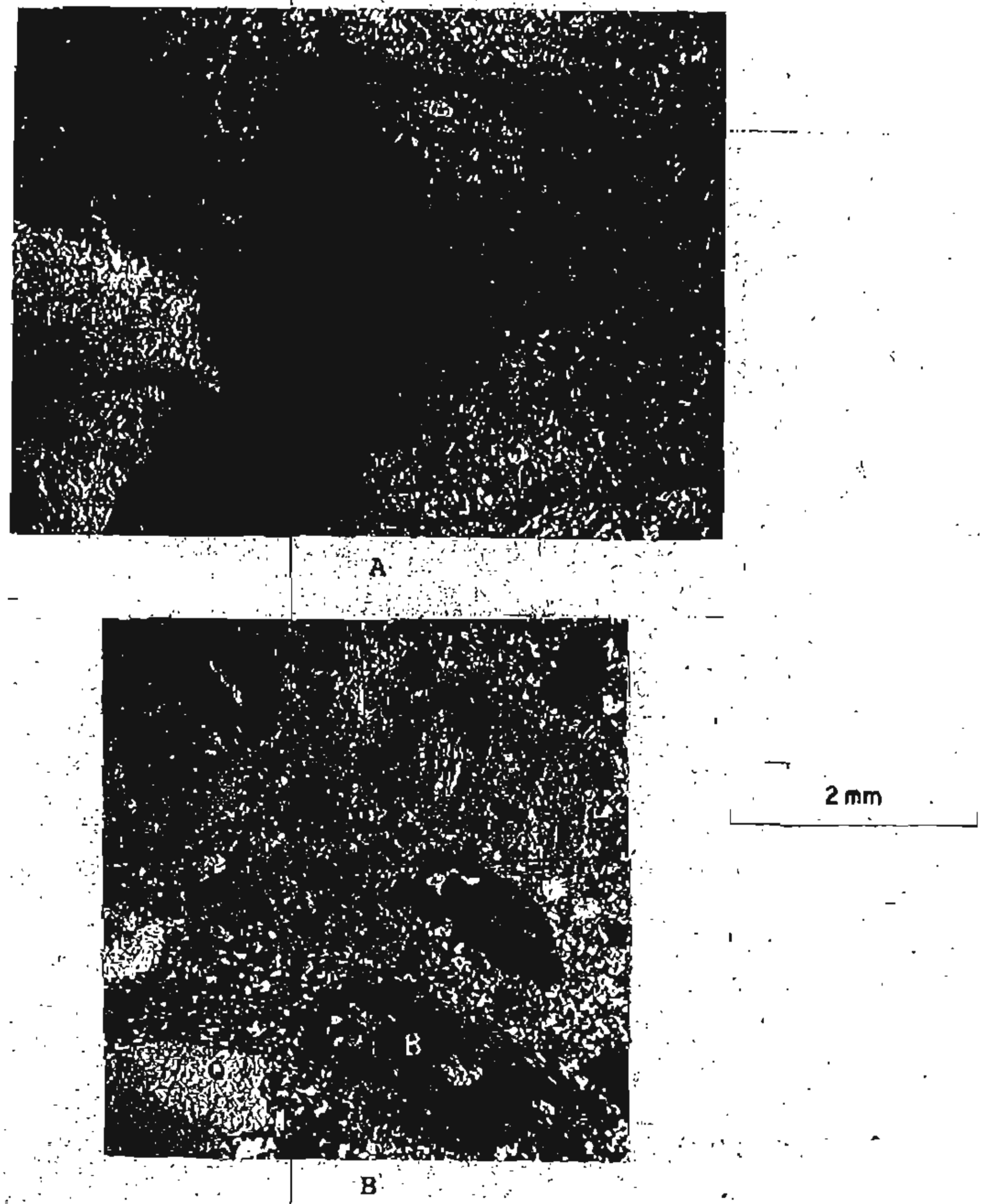


Figure 20. A. Quartz monzonite porphyry along tributary of Dark Creek. Lineation of some potash feldspar megacrysts subparallel to hammer handle.

B. Photomicrograph of quartz monzonite porphyry. M, microcline; P, sericitized plagioclase; B, biotite; Q, quartz. Crossed polars.

Veins and Replacements

Tourmaline occurrences

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

In thin section, schorl 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 dismembered 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 inches to 1 foot in width, all essential granite minerals except quartz have been selectively replaced. Minor fluorite and pyrite are associates.

Tourmaline veins are locally abundant. They are less than 1/2 inch thick and occupy planar fractures. The tourmaline occurs alone, with quartz, or with quartz, pyrite, and fluorite; at some localities it is altered to chlorite. Vein boundaries are mostly sharp. Rosettes are particularly abundant in some aplites, and in vicinities where muscovite, epidote, flourite, and sulfides occur, as along the north side of Dark Creek.

About 40 readings on tourmaline vein sets are plotted on plate 4. Most 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 are parallel with aplite dikes which also contain intergrowths of tourmaline. Veins also sharply cut these rocks, and are clearly later in age. Some veins are parallel to schistosity in the granite; in one such case, they cross biotite foliation, but others locally parallel the biotite foliation. None were found that cross 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 northerly-trending joints which are now so prominent (p. 191-192) may have been related to granite emplacement. It has not been established whether tourmaline veins cut quartz monzonite or mafic dikes in the granite.

Some cross-cutting 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 of N.65°E., 57°S which crosses biotite-rich schlieren having an attitude of E-W, 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 (1948).

Chlorite veins

Chlorite, chlorite-quartz, and quartz-chlorite-calcite veins are common 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 microaggregate different from the flaky aggregates resulting from the alteration of biotite. Veins composed wholly of chlorite are most common, are straight, and are mostly less than 3/8 inch thick. Bleaching effects along the veins extend to 1 inch into the granite and reflect biotite alteration and perhaps kaolinization of microcline. Chlorite of this type also occurs as vein-filling between large quartz crystals which line the vein walls.

The chlorite veins in granite belong to a late stage of mineralization. They cut aplites, quartz and tourmaline veins, quartz monzonite dikes, and quartz veins, although rarely, the latter cuts chlorite veins. Many chlorite veins are slickensided, and drag effects along one was seen in thin section. Some are displaced a few inches along later fractures. In a few vein localities chlorite of this type is associated with tourmaline and appears to be a replacement of that mineral. It is possible that many of these chlorite veins are complete replacements of tourmaline along selective fracture sets but they were seen to cross unaltered tourmaline veins at several localities and there are obviously due to later chlorite introduction. Fifty-six readings on chlorite vein attitudes (some on pl. 4) show that most of them strike roughly north and dip steeply to the west. They parallel prominent joints which are interpreted to be extension or longitudinal fractures (p. 194-196).

Quartz veins and replacements

Vein quartz is relatively common in the granitic rocks and all pre-Cretaceous clastic rocks in the area. Veins in granite range from a few inches to about a foot in width, 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 effects as evidenced by planar internal fractures which cross crystal clusters irrespective of individual crystal orientations and are parallel to planes of schistose foliation in the granite. Other veins of finely crystalline quartz show colloform structure, drusy surfaces, and are in some localities 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 above.

Attitudes of 58 quartz veins recorded in granite (pl. 4) indicate a north-northwest striking and steeply-dipping set and other less well-defined sets which roughly parallel the trend of the batholith. Along the northern 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 perhaps indicate crystallization in a shearing stress field or during continuous 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.

Approximately 60 readings on quartz veins in sedimentary rocks north and east of the granite (pl. 4) indicate strong control by northerly-trending steeply-dipping fractures. Quartz is particularly abundant in gash veins and stockworks near faults and in the axial areas of minor folds.

Data are insufficient to determine relative ages of most quartz veins although at least two stages of quartz introduction are probable in the granite. Some vein quartz is associated with tourmaline; none was seen to cut or be cut by tourmaline veins. Most vein quartz, however, clearly predates chlorite veins which are post-tourmaline. 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 planar 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 Dark 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.

Sedimentary rocks in the Romanzof Mountains are silicified to varying degrees. Whether this can be ascribed to granite emplacement, later orogeny, or other causes is not known.

Age

Laboratory evidence

Age determinations on two samples of the Romanzof granite by the U. S. Geological Survey include lead-alpha determinations on zircons and potassium-argon determinations on biotite. Sample 57ASa160 was collected at about the contact between porphyritic and variable zone facies and sample 58ASa188, 195 is from the variable facies. They were collected at relatively low altitudes along the east and west sides of the Okpilak River valley. Plans to collect from the coarse facies were abandoned because of the difficulty of backpacking large samples to the base camp.

The lead-alpha determinations reported April 25, 1960, by the U. S. Geological Survey are shown in table 10. The calculated age difference between the two zircon fractions from 58ASa188, 195 appear to be outside the expected experimental limits, and may be an experimental error or due to the presence of trace amounts of common lead in the magnetic fraction, according to T. W. Stern (written communication, 1960). Stern indicated that "we would select the younger age as probably being closer to the true age".

Potassium-argon determinations on biotite reported by the U. S. Geological Survey March 6, 1963 from the above two samples indicates considerably different ages from those determined by the lead-alpha methods. The K-Ar determinations are shown in table 11.

Table 10. Lead-alpha age determinations of zircon from Romanzof Mountains, Alaska

Field No.	α/mg-hr	Pb(ppm)	Calculated Age	
57ASa160	655	84 (80,88)	310 ± 35 m.y.	
58ASa188, 195 NM 1.5	538	80 (80,74,80,88)	360 m.y.	405 ± 45 m.y.
58ASa188, 195 M 1.5	747	140 (135,145)	450 m.y.	

The lead-alpha ages were calculated from the following equations:

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

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

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

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

Ages are rounded off to the nearest 5 m.y.
Lead determinations by Nola B. Sheffey
α counts by T. W. Stern
NM refers to non magnetic zircon fraction
M refers to magnetic zircon fraction

Table 11. Potassium-argon age determinations of biotite from Romanzof Mountains, Alaska

Lab. No.	Field No.	K_2O %	K^{40} ppm	$^*Ar^{40}$ ppm	% radiogenic Ar^{40}	$^*Ar^{40}/K^{40}$	Age m.y.
283 B	57ASa-160	7.59	7.69	.0596	89	.00775	128
284 B	58ASa-188-195	7.19	7.28	.0548	79	.00753	125

* radiogenic argon

Constants $K^{40}\lambda_{\epsilon} = 0.585 \times 10^{-10}$/yr. $\lambda_{\beta} = 4.72 \times 10^{-10}$/yr.

$K^{40} = 1.22 \times 10^{-4}$ gm/gm K

Potassium determinations made with Perkin-Elmer flame photometer with Lithium interval standard.

Overall analytical error approximately ± 5 percent.

Analysts: H. H. Thomas, R. F. Marvin, Paul Elmore, H. Smith

The lead-alpha dates fall into the Carboniferous or Devonian on the Holmes (1960) time scale and may suggest an Acadian, or less likely, Caledonian age for granite emplacement. The K-Ar dates are Lower Cretaceous. The wide discrepancies between the two types of age determinations may be explained by: 1) all deformation in the area is the result of one essentially synchronous Mesozoic granite emplacement, and the zircons represent constituents of older rocks, or 2) that a late Paleozoic granite has been affected by Mesozoic deformation and metamorphism. An answer to the problem of genesis of these granitic rocks is necessary to properly evaluate the age data; are the zircons the products of melt crystallization or do some represent grains which predated granite emplacement?

Results of examination of zircon in thin sections of granite in an attempt to recognize different color and shape varieties 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.

The writer feels that both age determinations may be valid, but that the lead-alpha dates are preliminary and it is difficult to specifically date a Paleozoic orogeny on only two analyses. The K-Ar dates probably represent a metamorphic episode roughly coincident with late Jurassic and early Cretaceous orogeny of which there is abundant evidence in the Brooks Range and adjacent areas.

Field evidence and interpretation

Field evidence for the age of the granitic rocks is not clear. The granite clearly post-dates rocks of the Neruokpuk Formation, but its relationships with the Kekiktuk Conglomerate and Kayak(?) Shale, units which locally overlie the granite, are uncertain. The base of the Kekiktuk is believed to overlie a regional unconformity. Relationships between granite and Kekiktuk rocks are gradational through a schistose zone and the Kekiktuk seems to be slightly altered (p. 147-149). The granite is nowhere known to definitely intrude or alter Kayak(?) or younger rocks. These relationships appear to narrow granite emplacement to pre-Kekiktuk time or post-Kekiktuk and pre-Kayak(?) time, and indicate that the granite may be Late Devonian in age. Other evidence which supports this view includes:

1. No recognizable inclusions of Kayak(?) or younger rocks were seen in the granite; the inclusions observed appeared to be most closely related to quartzitic rocks in the Neruokpuk.

2. No pegmatites, aplites, granite apophyses, or mineralization other than pyrite and quartz were seen in post-Neruokpuk rocks although quartz veins are common in all rocks, and one minute tourmaline crystal aggregate was seen in the Kekiktuk.

3. Bedding in Kekiktuk rocks adjoining granite-schist transitional zones is locally unconformable on granite feldspar foliation, as along the east side of the Jago stock.

4. Much of the granite is highly deformed, 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 have the appearance of having been subjected to two or more different stress directions as some of the older rocks do. The granite also exhibits divergent foliations and dislocations that are difficult to ascribe to one period and orientation of stress, although variable stresses during and closely following emplacement could explain these features.

5. The map pattern (pl. 1) strongly indicates that an unconformity of considerable magnitude lies at the base of the Kekiktuk and possibly Kayak(?) rocks. Its age would roughly coincide with the Paleozoic lead-alpha dates in the Romanzof granite.

6. Low-grade metamorphism of post-granite mafic dikes, which seems to correspond to alteration of biotite and tourmaline to chlorite in the granitic rocks.

If, however, the granite post-dates 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 probably related to orogeny accompanying granite emplacement. Field evidence which may support an Early Cretaceous age for granite emplacement includes:

1. The apparent lack of feldspar or other granitic debris in clastic rocks of Mississippian through Jurassic age. Feldspars similar to those found in the Romanzof granite are present, however, in sandstones ascribed to the Ignek Formation of probable Cretaceous age, as well as pre-granite Neruokpuk Formation rocks.

2. Fairly widespread silicification, quartz veins, and locally abundant disseminated pyrite in all pre-Cretaceous rocks.

3. The dominantly south-dipping cleavage in Mississippian-Jurassic rocks which parallels the biotite foliation in the northern part of the pluton. This is based upon the

assumption that the biotite foliation is associated with granite emplacement and not a later post-consolidation feature.

4. 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).

5. The lack of granitic material in Paleozoic rocks of the southeastern Brooks Range, although Cretaceous conglomerates contain granitic debris (Brosge, 1962, personal communication).

Gradations from enclosing schistose rocks into granite are abundantly reported in the literature (Grout, 1943; Turner and Verhoogen, 1951, p. 284), and the schists are generally interpreted to be older than 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 Romanzof granite, upon which effects of a later orogeny are superimposed. Possible explanations for a post-granite age of the apparently transitional rocks depend on the assumption that their schistosity, cleavage in overlying rocks, and biotite foliation in the underlying granite 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) products of metasomatism by local diffusion of material from the granite into quartz sandstones and pelitic rocks during a later orogeny; 2) a metamorphosed pre-Kekiktuk regolith rich in iron oxides, quartz grains, and remnants of partially weathered microcline megacrysts and altered biotite; 3) metamorphosed zones along low-angle thrust faults. The first speculation may have some merit; the others are doubtful. It would seem that 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 anisotropic sequence, the Kekiktuk should form the base of allochthonous blocks in widely separated areas.

The writer favors the view that the Romanzof granite is an Upper Devonian [pre-Kayak(?)] pluton in which biotite age has been updated by Mesozoic orogeny. The older age is strengthened by a 353 m.y. K-Ar date for quartz monzonite in the northern Yukon Territory (Baadsgaard, Folinsbee, and Lipson, 1961, p. 459), and by regional tectonic considerations (p. 202-209). Granitic rocks dated in the eastern Brooks Range (Brosgé and Reiser, 1964) include a granite at Chandalar Lake in which a Pb-α age on zircon and a K-Ar age on biotite are 380± 40 m.y. and 125 m.y. respectively. The Pb-α ages need verification, according to Brosge (personal communication, 1962), who favors a Mesozoic age for the pluton.

Mode of Emplacement

The Romanzof 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 had an elongate funnel-shape in cross-section and contained multiple centers of intrusion, as inferred from its primary foliation trends and the apparent textural facies distribution shown on plate 5. Features from which a melt origin is inferred include:

1. The rather uniform compositional nature of the granitic rocks irrespective of the nature of truncated country rock.

2. Sharp and irregular contact relationships in an area of low-grade 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; metamorphic textures are common throughout the pluton, however.

6. Included crystals showing sharp boundaries with their hosts.

Cataclastic (autoclastic?) textures probably 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 wall rock. The melt was probably relatively dry, as reflected by the scarcity of pegmatite and minor areas of mineralization ascribed to volatile materials. Deformation continued into the deuteric stage. Possible reasons for origins of the textural facies have been given on page 133. Structureless granite, locally present in the coarse inner facies, appears to have crystallized following the orogenic maximum.

The low metamorphic degree and lithologic character 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.

MAFIC HYPABYSSAL AND VOLCANIC(?) ROCKS

Distribution, Character, and Composition

Tabular bodies of greenish metamorphosed basalt (greenstone) occur in several areas of the Romanzof granite and in Neruokpuk Formation rocks (pl. 1). A relatively large area of similar rock types, in part amygdaloidal, as well as purple and gray aphanitic rocks are exposed along the Hulahula River. 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. Although at most places dike walls are sheared, locally the dikes contain inclusions of country rock and chilled border phases. In most exposures, primary features of these dikes have been masked by schistosity and mineralogical alteration. They consist of sericitized plagioclase microlites, epidote, sericite, and chlorite, with felted texture. Some are entirely chlorite-sericite rock with highly fractured garnet metacrysts.

Mafic flows(?) covering about 6 square miles along the Hulahula River have been reported by Leffingwell (1919, p. 26) and Whittington and Sable (1948, p. 16; 1960, p. 20-21). Mineralogy of these rocks is indistinguishable from that in 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 reports augite, plagioclase, and a little quartz in these greenstones. Purple, greenish, and gray aphanitic rocks with slaty cleavage along the Hulahula River are probably genetically associated.

The metamorphosed basalts along the Hulahula have been interpreted to be of volcanic origin, and perhaps lie near a volcanic vent (Whittington and Sable, 1960). Rocks of generally similar appearance occur in northeastern Alaskan areas, such as the Sadlerochit Mountains (Whittington and Sable, 1948, 1960) and east of the Romanzofs (Mangus, 1953, p. 18-19). Some 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 Romanzofs, was examined by the writer. The rock is a gabbro with diabasic to ophitic texture, and contains plagioclase, about An_{70} (51.9%); augite (31.1%); graphic intergrowths of quartz and feldspar (7.4%); magnetite (5.9%); and quartz (3.7%).

Age

Because of their apparent compositional similarity, the mafic rocks in the Romanzof Mountains and other areas of northeastern Alaska are inferred to be cogenetic. Field relationships indicate that the mafic dikes are clearly younger than many units of the Neruokpuk Formation in the Romanzofs and also post-date the Romanzof granite. Their upper age limit is not known. An apparent tongue of mafic rock projecting into rocks of the lower Lisburne Group along the Hulahula River (pl. 1) was examined, but no bedrock contacts were seen. The "tongue" lies in a tight complexly faulted anticline. Rubble of Lisburne Group rocks adjoining the mafic rocks locally appears brittle and ironstained, but no certain contact effects were observed. The consistent outcrop pattern shown by Whittington and Sable (1960) along the Hulahula River strongly suggests that the Kekiktuk-Kayak(?) unit of this report unconformably overlies both the mafic rocks and Neruokpuk Formation. The mafic rocks are here provisionally considered to be Upper Devonian, although somewhat similar mafic rocks in central- and western-northern Alaska are referred to the Mesozoic (Dutro and others, 1951, p. 18).

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 map area. North of the pluton, a regional northerly dip prevails which is interrupted by large anticlinoria west of the Hulahula River and probably anticlinal structures of lesser magnitude in the coastal plain between the Hulahula and Jago Rivers.

Within the map area north of the Okpilak batholith, folds include east-northeasterly trending anticlinal and synclinal structures from 1 to more than 6 miles in breadth with amplitudes of as much as 2000 feet. The major structures outlined above contain numerous smaller-scale structures including folds which range from a few feet to several hundred feet in breadth 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 towards the granite, and rocks in a belt 1/2 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, 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 1000 feet wide. Although this seems to represent a zone of shearing deformation with accompanying retrograde(?) metamorphism, structural evidence 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 in Neruokpuk carbonate rocks and cross-cutting 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. 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 post-granite-emplacement thrust fault.

Major structures east of the Jago River, northeast of the Jago stock, trend east-northeast and include, 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.

Structural cross-sections are shown on plate 2. Of interest is the striking coincidence of present topography north of the Okpilak batholith with broader folds. This may simply reflect resistant bedrock units which now control local levels of erosion, or it may indicate that broad folding was relatively recent, perhaps late Tertiary or younger in age.

As a whole, the sedimentary rock mass in the Romanzofs is structurally anisotropic, containing alternating competent and incompetent units. The latter, such as the shale 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

Neruokpuk Formation, but subsequent silicification and recrystallization have resulted in highly competent rocks. The carbonate rocks of the Lisburne Group are also competent and failed mostly by rupture, although tight folding is evident in some localities. The granitic rocks are highly competent and have yielded by faulting, granulation, and the local development of schistose and gneissic structures.

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 foliation (p. 153-154) within parts of the batholith. The orientation of joints, cleavage, and schistosity are shown on plate 4.

The relatively broad second order folds shown on plate 3 strike east-northeast, appear to be asymmetric with axial planes dipping south, 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. Interpretation of structural continuity across the

Jago River is also uncertain; possible dislocations which are obscured by glacial material may lie along the Jago River valley or the lower part of McCall Creek. Along the northern front of the granite, closely spaced structure contours reflect a steepening of dip combined with imbricate thrusting and overturning of adjoining sedimentary rocks. The stratigraphic succession exposed in this belt, however, does not indicate large-scale dislocation, but suggests that the granite, directly underlying post-Neruokpuk rocks, may be in high angle reverse fault relationship rather than forming the sole of an overthrust.

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 former are more variable. These folds are best developed in the upper two members of the Sadlerochit Formation, even where the underlying beds show little evidence of deformation (fig. 21).

Cleavage and Schistosity North of Okpilak Batholith

Slaty cleavage due to parallel orientation of minerals is well developed in rocks of Mississippian through Jurassic ages north of the granite (pl. 4). The cleavage strikes N.60°-80°E., dips predominantly south, and is consistent with general fold trends as well as secondary foliation in the northern part of the pluton. Cleavage was not recognized in some places near the mountain front; it may be locally coincident with bedding. Elsewhere, cleavage is relatively consistent in trend, closely parallels third order fold axes,

Figure 21. Oblique view 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; ma, mafic rocks; Mk, Kekiktuk Conglomerate and Kayak(?) Shale; Ml, Lisburne Group; Psf, Pss, Psq, members of Sadlerochit Formation (see text). Ridges north of mountains composed of Kingak Formation. Photo by U. S. Navy.

and exhibits only local deviations across bedding interfacies. 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 and probably second order folds, although the latter may in part stem from differential uplift following the orogenic maximum. Cleavage is also considered to be related to biotite foliation and schistosity in the adjoining granitic rocks (pls. 4 and 7), as well as schistosity in the narrow belts of schistose rocks along the north margin of the batholith. Schistose foliation in these belts has a low to moderate south dip which generally corresponds to axial plane attitudes of folds in the adjoining sedimentary rocks. All of the above features are interpreted to have resulted from north-northwest compressive stress during a Mesozoic (Early Cretaceous?) orogeny; the second order folds may have formed following the orogenic maximum.

Faults

Faults having apparent displacements from a few feet to more than 1000 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 include:

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 stratigraphic displacements of from tens of feet to 1200 feet. There is marked silicification and brecciation along some of the larger faults, and quartz-filled fractures associated with fault trends are common. Striated slickensides, where seen, are mostly steeply dipping, although some horizontal or shallow dipping striae attest to strike-slip movement. Of 19 recorded striations, 18 are on steeply dipping fault planes. Twelve of these ranged from 65° to 90°, and 7 ranged from 0° to 26°. Most of these were recorded on south- or west-dipping fault planes.

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 the maxima 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 limbs in a late stage of isoclinal folding.

3. Low-angle thrust faults of apparent large scale. East of the Jago stock; Neruokpuk Formation quartzites, slates, and minor granite have overriden Lisburne Group rocks. The exposed margin of the block dips southeast from nearly flat-

lying to about 45 degrees. Other thrust faults are inferred south of both the Jago stock and the Okpilak batholith, and the southern limit of the latter may in part coincide with a thrust fault, as suggested by zones of intense deformation along the east fork of the Okpilak River. Sugary-textured silicified zones in the granite related to probable shallow to moderately dipping thrust faults west of McCall Glacier are described on page 166.

4. Shear zones in the granitic pluton are discussed on pages 154-156. They are well expressed along the east wall of the Okpilak valley, 3 to 4 miles south of Okpilak Lake.

Other common features in the granitic rocks are linear zones to irregular areas as much as 2000 feet wide and 1 mile long which are highly stained by iron oxides (pl. 1). These are areas of weak sulfide (mostly pyrite) mineralization, and although many adjoin faults, show shearing effects, and are associated with granite of cataclastic texture, others appear to be disseminations in mildly fractured and bleached granite.

In addition to the faults described above, hypothetical north-trending fault zones affecting at least pre-Mississippian rocks and granite may be concealed by glacial and alluvial material along portions of the major river valleys. Structures in rocks on the west and east walls of the Jago valley between the Jago stock and the mountain front indicate a sharp northward swing in strike along the valley, but the Jago stock itself does not appear to have been displaced. Along the east valley wall of the Okpilak River, numerous north-trending shear zones, faults, and linear ironstained 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 valley, west of the map area, Triassic rocks are exposed on the west side of the river (Whittington and Sable, 1960, map) but rocks of pre-Mississippian age constitute the east valley wall; a major dislocation with the east side up is inferred here. North of this, if one assumes that the mafic volcanic(?) rocks along the Hulahula overlie the Neruokpuk Formation, a fault along the east boundary of the volcanics(?) with the east side upthrown can also be inferred. Although speculative, these inferences are strengthened by the fact that steeply-dipping north-trending faults parallel to portions of major stream valleys are common in the Romanzof Mountains. 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 zones of shear caused by movement of the competent granite against its wall rocks during a later orogenic maximum.

Longitudinal and thrust faults are ascribed to northward tangential movement, probably Cretaceous in age. The Okpilak batholith itself probably moved upward and northward resulting in zones of shear along its north front and the overturning and imbricate faulting in the adjoining sedimentary rocks.

The northerly-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 modified by erosion.

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 4. Pole maxima 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.-S. to N.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. In subareas III and IV, west of the Okpilak River, N.30°W. to N.45°W. strikes are conspicuous, and generally parallel the transverse fault pattern. Less well developed east-northeast striking, steeply-to moderately-dipping joint sets in subareas I-IV are interpreted to 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. Although they may represent part of a radiating tensional joint pattern around the batholith, such a pattern is not evident in the area studied. Slickensided surfaces along some of the joints show evidence of small displacements; this, and their general parallelism to the transverse fault pattern suggest that they may have predated these faults and controlled their trends.

Joints in Granitic and Adjacent Rocks

Joint patterns in the granitic rocks of the Okpilak batholith and the adjoining Neruokpuk Formation are represented by more than 500 readings, shown on plate 4. In general, 3 to 4 sets of joints are present at most localities in the granite. The contour patterns show more random distribution of pole maxima than in rocks north of the batholith and indicate several moderately- to steeply-dipping joint sets. The steeply-dipping north- and northwest-striking sets north of the batholith are developed here also, but the northwest-striking set has a more shallow westerly dip component than in the sedimentary rocks.

The most prominent joint and fracture sets in subareas V-VII and IX include:

1. Joints striking N.30°-45°W. and dipping moderately to steeply west to vertical. They parallel some chlorite veins,

many quartz veins, many normal faults north of the granite, and 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 several minor irregularities along the south and north margins. Linears probably representing this joint set are prominent on aerial photographs in the eastern two-thirds of the batholith;

2. Joints striking N.-S. (±20°) with steep to vertical dips. These are closely parallel to many chlorite and quartz veins, some shear zones in the granite, and locally parallel primary foliation features in subareas V and IX. Well developed linears seen on aerial photographs in the western part of the batholith probably reflect this joint set.

3. Joints striking N.30°-45°E. (to N.60°E. in subareas VI and VII) and dipping moderately to steeply south and north. Pole maxima showing moderate dips in subareas VI and IX represent mutually conjugate sets. The strike of these joints is sub-parallel to the elongation of the batholith and locally coincides with schistosity and feldspar-biotite foliation trends in the south-central and eastern parts. Linears trending N.45°E. are prominent on aerial photographs in the eastern part of the batholith.

4. Joints striking roughly E-W (±15°), commonly west-northwest, and 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 northerly 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 similar relationship may be present in subarea IX. Overall sporadic distribution of vein attitudes, however, indicates that they are not consistently controlled by the joint patterns shown in plate 4.

In and near the Jago stock (subarea VIII), the equal-area projection shows a pattern somewhat similar to that in subarea IX. Joints in subarea VIII include essentially vertical joint sets striking E.-W. and N.60°E.; moderately- to steeply-dipping, possibly related sets with N.30°W. to N.45°W. strikes; and a north-south set dipping 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 western half of the exposed body.

Joint sets 1 and 2 above 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 so that, for example, N.15°W. joints in some subareas may genetically represent part of the N.30°-45°W. set in others.

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 those 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. The writer believes that a combination of these causes is likely; the fracture systems initiated during consolidation of the granite probably controlled later dislocations.

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 may have been reactivated as slip-surfaces during a later orogeny and controlled directions of normal faults. Joint sets in rocks north of the pluton corresponding to 1 and 2 are considered to be extension and shear joints respectively, and to be generally contemporaneous with the northerly-trending normal faults.

Joints of set 3 may correspond to the inward-dipping joints of Balk (1937, p. 109), indicating that stresses were directed upwards 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 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 which originated in the granitic rocks 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. A simple hypothetical stress field can roughly accomodate many of these (fig. 22), and is based on the assumption that north-northwesterly joints represent extension jointing. The complexity of the joint pattern and variability of other planar features in the eastern and southern parts of the granite, however, indicate that this construction is highly oversimplified.

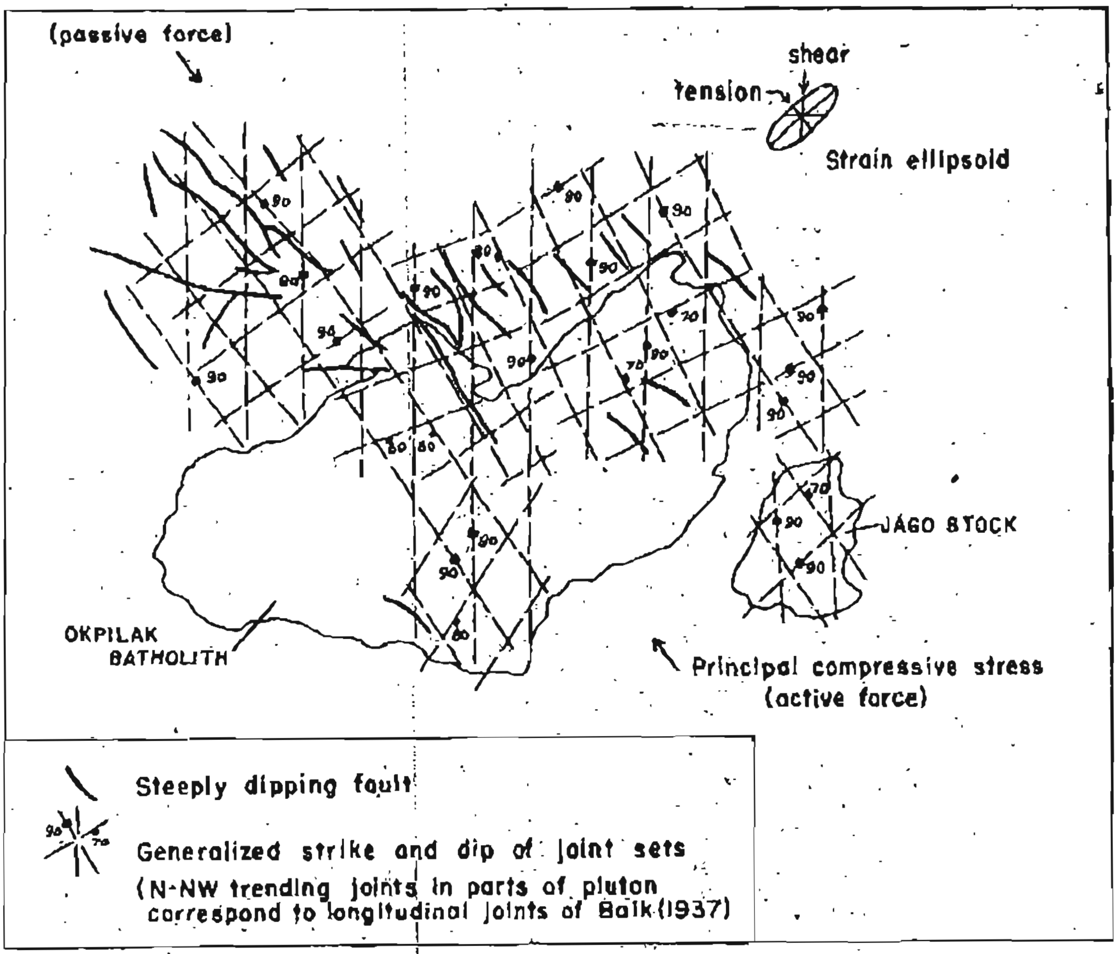


Figure 22. Plan view of Romanzof Mountains area showing selected prominent joint set and fault trends resulting from hypothetical stress field.

TECTONICS

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 recently been summarized by Eardley (1962, p. 605-649); those in Canada are based upon several published regional syntheses, and those in Alaska mostly from areal reports. The following discussion suggests the possibility that a late Paleozoic orogenic belt accompanied by granitic intrusion has affected northern Alaska but has largely been masked by Mesozoic events (see fig. 23).

The dominant structural features in northern Alaska are the result of Mesozoic and early Tertiary deformation. Major Mesozoic and Cenozoic elements reported by Payne (1955) are well established, and include the Brooks Range geanticline, a linear east-trending feature more than 600 miles long, flanked on the northeast by the Romanzof uplift and by the Colville geosyncline farther west. South of the geanticline one of several northeast-trending elements is the Ruby geanticline, which joins(?) 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 is characterized by the development of large, complex, mostly west plunging

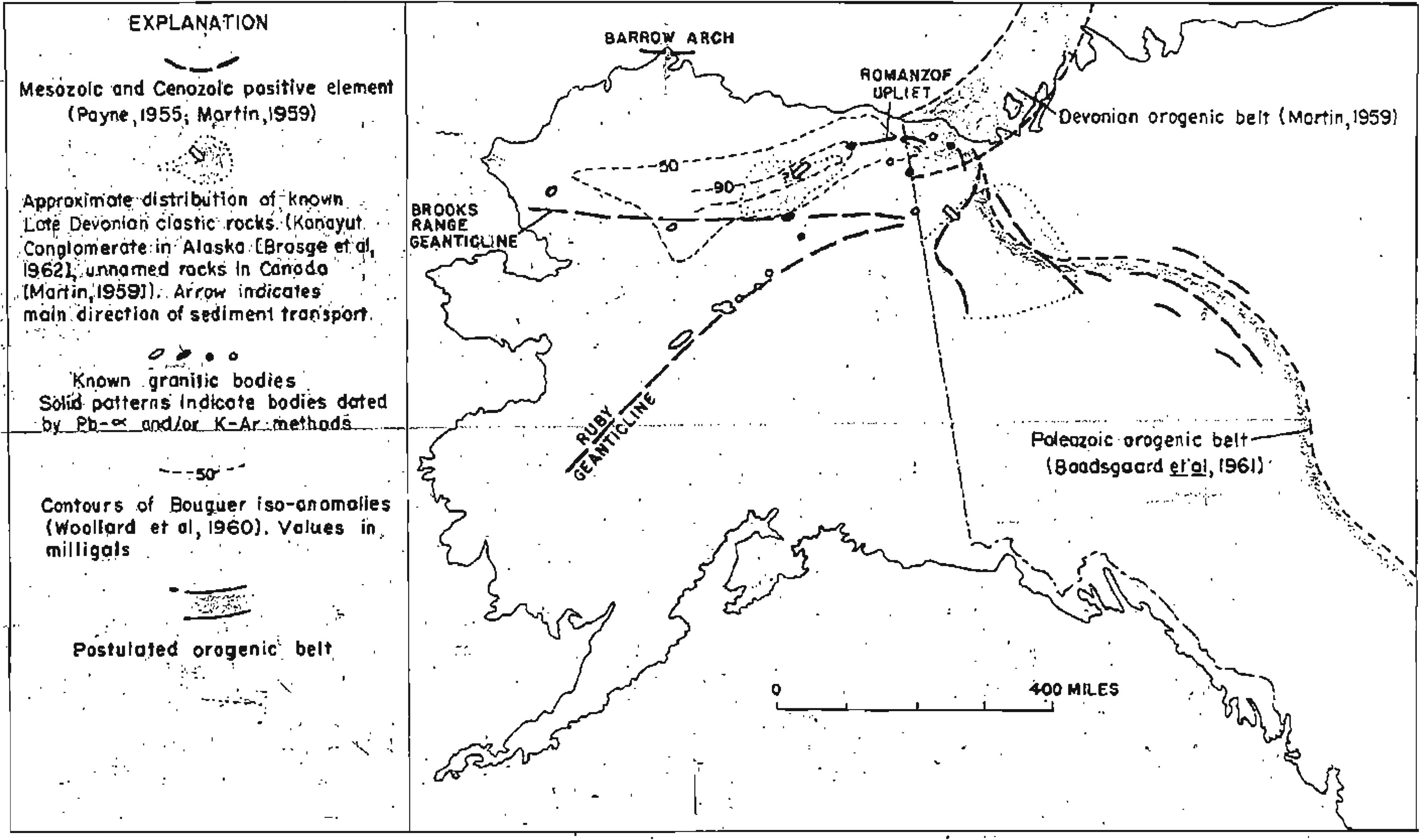


Figure 23. Map of mainland Alaska and northwestern Canada showing selected major tectonic features.

anticlinoria and synclinoria. Structural features similar to the Brooks Range geanticline are present in the Romanzof uplift, but deformational intensity there is not as strongly expressed. 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 Wyoming Rockies.

In the Yukon Territory, positive elements of late Cretaceous or early Tertiary age (Martin, 1959, p. 2451) strike mostly southeast and south towards 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 but of less magnitude than those in the Alberta Rockies. 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 Arctic Islands to the northeast. Martin (1961, p. 451) indicates, however, that a nearly continuous depositional basin striking from the Romanzof uplift to Ellesmere Island was present during the Mesozoic.

In general, known Paleozoic sedimentary rocks in northern Alaska are considered to represent miogeosynclinal or shelf sedimentation; those in the northern Yukon Territory appear to be similar. Southern Alaska, however, was a great eugeosynclinal region during the Paleozoic (Gates and Gryc, 1963, p. 268-269). Paleozoic orogeny and granitic intrusion in northern Alaska, therefore, would appear to be continentward from the southern eugeosyncline (Eardley, 1962, p. 610). However, Martin (1959, p. 2442) has postulated a Paleozoic eugeosyncline lying 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; exposed granitic plutons are very rare west of longitude 150°, but several occur farther east. The northernmost of these is the Romanzof granitic pluton, in the Romanzof uplift; the remainder lie in the Brooks Range geanticline province. Southwestward in Alaska, the Ruby geanticline contains large belts of granitic rocks along its trend (Dutro and Payne, 1957) which have not been dated by radioactive 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.

Potassium-argon dating of biotite in three Canadian granitic rocks 150 to 250 miles east of the Romanzof Mountains indicates ages of 353, 220, and 95 m.y. (Baadsgaard, Folinsbee, and Lipson, 1961). The investigators, however, indicate that the three plutons may be cogenetic and that the younger ages, especially 95 m.y. may represent updating of older granites by later orogeny. The same authors tentatively postulate a Paleozoic orogenic belt extending south-southeastward from the Arctic Ocean near the Alaska-Yukon boundary to Montana. In relating an orogeny about 350 million years ago to the stratigraphy of northeastern Alaska, the writer agrees with Baadsgaard and others in placing it prior to Mississippian time and not older than Middle Devonian. The writer would consider it to be Late Devonian if the upper units of the Neruokpuk Formation are Late Devonian, and the Kayak(?) Shale is Mississippian in age.

Martin (1961, p. 449) states that an orogenic maximum occurred in Late Devonian time in northwestern Canada, and indicates an orogenic belt across the northern part of the Canadian Arctic Islands and northern fringe of the western mainland. He shows the belt to strike southwestward and westward towards the Romanzof area, rather than joining the southwesterly-trending belt as shown by Baadsgaard, Folinsbee and Lipson, (1961). Martin's tectonic portrayal is based upon regional interpretation of stratigraphy and structure and seems more plausible to this writer than the more tenuous connections with the Rocky Mountain trend arrived at by widely spaced age-dating.

Assuming that Martin is correct in his westward extension of the Arctic Islands Paleozoic orogenic belt, three continuations of this belt are possible in Alaska: 1) the belt may have extended westward from the Romanzof 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 parallel to the Mesozoic Ruby geanticline; 3) it may roughly coincide with the later Brooks Range geanticline. Different lines of evidence are suggested below for each of the possibilities. Evidence and interpretations are shown on figure 23.

Interpretations of the Devonian sequence described by Brosge and others (1962) in the eastern Brooks Range support the first possibility listed above, and may indicate that a Late Devonian orogenic maximum is reflected by outpouring of the Kanayut Conglomerate, which was deposited in an east-northeast trending basin about 50 to 200 miles south of the Romanzofs. In the eastern Brooks Range, thicknesses and lithologic distribution of the Kanayut are indicative of a northern source area, perhaps in the Romanzof area or farther west. In the Yukon Territory, 75 miles southeast of the Romanzofs, similar coarse Upper Devonian clastics (Martin, 1959, p. 2442-2443) indicate a northwesterly source area representing the Upper Devonian orogenic belt, which Martin places in the British and Barn Mountains area, but could easily include the Romanzof area as well. From this evidence it would appear that the Upper Devonian positive belt might have trended westward across northern Alaska, perhaps through the Point Barrow area, where a major structural element, the Barrow Arch (Payne, 1955) exists. Pre-Mesozoic rocks in wells drilled in the Barrow and Cape Simpson areas include dark argillites similar to the Neruokpuk Formation which are unconformably overlain by Triassic and Jurassic rocks (Collins, 1961); Robinson, 1959).

Distribution of granitic plutons in the eastern Brooks Range and Ruby geanticline suggests the possibility that a Paleozoic orogenic belt may have roughly coincided with the Ruby geanticline, rather than parallel to the continental margin. These plutons have not been dated, and until they are, this possibility is merely speculative. The regional patterns of Upper Devonian clastic sedimentation in the eastern Brooks Range, and the abnormally thin Kekiktuk-Kayak(?)-Lisburne Group sequences in the Romanzof area do not preclude such a possibility.

Results of gravity work in Alaska (Woollard and others, 1960), show a belt of strong negative anomaly which extends from the British Mountains westward and southwestward to the western Brooks Range. The most pronounced trough trends southwest from the Romanzof Mountains, corresponds with the Romanzof uplift and northern part of the Brooks Range geanticline, and generally agrees with the pattern of granitic pluton distribution in northeastern Alaska and northwestern Canada. The gravity low (fig. 23) may reflect either crustal composition or thickness, but in either case can plausibly be related to the root zone of an orogenic belt. The belt of most intense Mesozoic and Cenozoic deformation trends east, at an acute angle to the gravity trough. The trough may therefore represent a late Paleozoic orogenic belt which has been largely masked by Mesozoic orogeny. The thick Kanayut Conglomerate sequence, however, lies within the trough, and if structurally autochthonous, indicates that a depositional basin existed there during Late Devonian time. Considering the numerous Mesozoic northward-thrust elements of the central Brooks Range, the writer feels that the Kanayut may lie in an allochthonous block which was moved far north of its original site during Mesozoic or later orogeny. The view that a late Paleozoic orogenic belt is reflected by the gravity trough is therefore tentatively favored by the writer.

From the foregoing, it is evident that trends and positions of Paleozoic tectonic elements in northern Alaska remain largely unknown, and the possibility that a Paleozoic orogenic belt existed in northern and central Alaska needs further study. The sketchy evidence cited above, however, is intended to be a hypothetical framework for future work and thought. With continued perfection of age determination methods, further field work, and the establishment of a more firmly substantiated tectonic framework for the Arctic basin by American, Canadian, and Soviet investigators, answers to this intriguing tectonic problem should be forthcoming.

ECONOMIC GEOLOGY

The mineral resource potential of the Romanzof Mountains is not well known. Some prospecting for gold has been carried on at the forks of the Okpilak River, but no systematic exploration has been conducted. During the present studies, general observations indicate minor amounts of mineralization at many localities, mostly in granite and rocks of the Neruokpuk Formation. These deposits appear to be mainly controlled by fractures, sheared zones, and areas of tactites. Pan samples were taken in 15 localities in Okpilak and Jago River drainages, but no precious metals were observed. Eleven stream silt samples, collected for analysis of trace metal content, are reported on below.

Metallic minerals include mostly pyrite, with lesser amounts of molybdenite, pyrrhotite, magnetite, arsenopyrite(?), chalcopyrite, chalcocite(?), and galena. Fluorite is sparsely disseminated in some sheared granitic rocks and greisen.

Pyrite in granitic rocks occurs finely disseminated along narrow linear zones and over broad areas as much as 2000 feet wide (p. 1), and also in veins intergrown with quartz, or with quartz, tourmaline, and fluorite. Disseminated pyrite occurrences commonly coincide with zones of sheared and schistose granite, 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 silica; pronounced gains in sulfur, soda, and titania; pronounced losses in iron oxides and potash; and some loss of lime and alumina. 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. The ratios of plagioclase to microcline in thin section appear to be reversed but this may be due to sample selection. Highly sericitized plagioclase (oligoclase-albite?) in the unaltered specimen is in contrast to relatively fresh albite(?) in the altered rock. The main changes are addition of sulfur and silica and removal of iron. Pyrite and/or marcasite also are disseminated in the shale member of the Sadlerochit Formation near the Okpilak River, and occur more sparsely in all post-Neruokpuk sedimentary rocks.

Some pyrite-quartz veins which cross-cut granite show strong crystal parallelism with 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 may be suggestive of two episodes of mineralization, one which was contemporaneous with strong deformation and the other post-deformational.

Molybdenite occurs as scattered single crystals and crystal aggregates less than one-half inch diameter in relatively fresh granite. It was particularly noted in glacial debris and a few outcrops in the vicinity of Leffingwell Glacier; elsewhere it is very rare. Although seen in several parts of the area, molybdenite does not seem broadly distributed or visibly concentrated to constitute even low grade deposits.

Pyrrhotite and magnetite are locally abundant as fine disseminations and bands less than 1/4 inch wide in dark hornfels and tactite adjoining the granite along Met Creek and Esetuk Glacier. Mineral associations and textures have been described on pages 140-142. In the Esetuk Glacier vicinity, magnetite is in concentrations large enough to affect the compass needle; it occurs as small pods in dark tactites.

Chalcopyrite and galena were found as small grains in sheared quartzose granitic rocks at their contact 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 Boulder Creek. Galena, sphalerite(?), and chalcopyrite occur at sheared contacts between granite and quartz-monzonite dikes along a tributary of Dark Creek. Here the minerals are in highly deformed pods or stringers a few inches in width consisting mostly of ironstained vein quartz, pyrite, and schistose rock. Their introduction was concurrent with, or preceded the shear stress. Galena is deformed so that the cubic mineral cleavage is hardly recognizable.

Purple fluorite occurs as veinlets associated with fine quartz and pyrite and as disseminated small grains in greisen rocks. Tourmaline is a common associate, and the two appear to be essentially contemporaneous in the exposures examined.

The stream silt samples were taken with the view of increasing knowledge about the distribution and abundance of trace amounts of metallic elements in Alaska, a current investigation in which the U. S. Geological Survey is engaged. Analyses by the U. S. Geological Survey, Denver, Colorado, are shown in table 12. All elements determined by field methods are shown, but only those determined by spectrographic methods which are considered to be higher than normal background for Alaska, according to R. M. Chapman (written communications, 1959-1961), are included. Chapman indicates that the lead content is "...slightly higher than... samples from the upper Koyukuk and in the Yukon Rivers region.", and that "I would regard 150 ppm Pb as anomalous". The relatively high content of uranium in biotite of the granitic rocks (White, 1952) may have in part contributed to the lead content of these samples. The analyses also suggest that beryllium and tin values may be higher than normal background; this type of mineralization might be further investigated.

Except for pyrite, none of the ore mineral localities seem to be widely distributed or traceable for more than a

Table 12. Trace element analyses of stream silt samples, Romanzof Mountains, Alaska.

U.S.G.S. Serial No.	Field No.	General Location	Pb	Cu	Zn	As	U	W	Sb	*Be	*Mo	*Sn	*La
59-2441	57ASa36	Jago River tributary, 2.5 miles south of McCall Creek	50	20	100	40	20	20	1	7	10	30	50
59-2442	57ASa88	Boulder Creek	50	10	50	20	12	<20	<1	2	<10	15	100
59-2443	57ASa161	Okpirourak Creek	25	20	100	30	8	<20	<1	10	<10	10	100
59-2444	57ASa162	McCall Creek	50	10	50	10	4	<20	<1	2	<10	15	100
59-2445	58ASa42a	Okpilak River tributary, 1.5 miles south of Dark Creek	50	10	50	10	12	<20	<1	3	<10	10	70
59-2446	58ASa54	Dark Creek	25	20	50	40	8	<20	1	2	<10	<10	100
59-2447	58ASa62	Okpilak River tributary, 4 miles south of Dark Creek	50	20	100	30	12	<20	<1	2	10	30	100
59-2248	58ASa125	Esetuk Creek	25	20	50	20	8	<20	<1	3	<10	10	70
59-2449	58ASa169	Leffingwell Creek	75	20	50	20	8	<20	<1	7	<10	20	70
59-2450	58ASa194	Split Creek	150	20	75	20	12	<20	<1	10	10	10	100
59-2451	58ASa206	West fork of Okpilak River	25	20	50	20	<4	<20	<1	<1	<10	<10	50

Numbers represent ppm.

*Determined by semiquantitative spectrographic analyses; analyst, E. F. Cooley. Other elements determined by field methods; analyst, J. McHugh.

few tens of feet; they do not appear to be in sufficient quantities to be of economic value. Large areas in the Romanzofs remain to be explored, however. It is suggested that carbonate rocks of the Neruokpuk Formation along the western and eastern margins of the Okpilak batholith, might be favorable areas for exploration.

The Shublik Formation may be a potential source of phosphate rock. Two samples have been analyzed in the Romanzof area. Patton (1959, p. 12) reports 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 analyzed by G. Chloe and S. D. Botts, U. S. Geological Survey, gives a value of 4.7 percent P_2O_5. Patton reports values as high as 35.8 percent P_2O_5 from the Shublik in northeastern Alaska.

There is probably no petroleum or gas potential in the area. Possible source rocks which may indicate potential in areas north of the Romanzofs include the organic shales and limestones of the Shublik Formation and thick black shales of the Kingak Formation. Potential reservoir rocks include those of the Lisburne Group, particularly the lower sandy limestones of the Alapah Limestone and the coarse crinoidal rocks in the Wahoo(?) Limestone. In the Romanzof area, both of these are capped by relatively impervious rocks, and the top of the 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 by the writer in the Romanzof Mountains and in other areas in northeastern Alaska appear to be relatively tight and impermeable, but Cretaceous and Tertiary sandstones northwest of this area are more poorly consolidated.

CONTRIBUTIONS AND SUGGESTIONS FOR FUTURE WORK

The work reported here has established a geologic framework in which future detailed studies can be made. In an almost unknown area 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 is not yet mapped.

It is suggested that future studies in this area include:

1. Detailed mapping of the western and southeastern interior portions 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. Concentration on the Kekiktuk-Kayak(?) boundary to evaluate their relationships;

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 pre-Permian unconformity;

9. Age determinations of the inner parts of the Okpilak batholith and of metamorphic rocks around its periphery.

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EXPLANATION

Unconsolidated deposits

Qac

Alluvium and colluvium
(Includes some glacial
material and terraces
above present floodplains)

Qc

Colluvium

Qg

Qg_5

Qg_4

Qg_3

Qg_2

Qg_1

Glacial and glaciofluvial deposits
(Subscripts 1 through 5 represent
First through Fifth advances)

QUATERNARY

Approximate outer limits
of glacial moraines
(Bent hachures indicate
direction from which
ice moved)

Sedimentary and Metasedimentary
rocks

Ki

Ignek Formation
(Sandstone, shale, coaly shale)

CRETACEOUS

JK

Jurassic and Cretaceous
rocks undivided

Jk

Kingak Formation
(Black shale and siltstone)

JURASSIC

Rs

Shublik Formation
(Limestone, shale, sandstone)

Psq

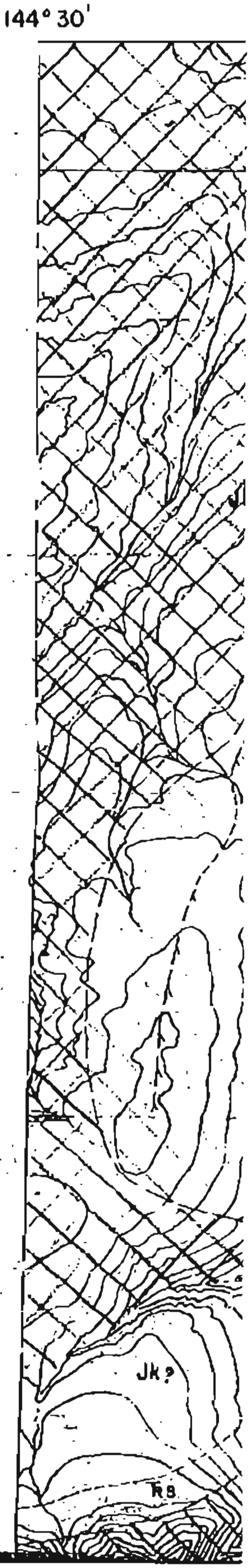
quartzite member

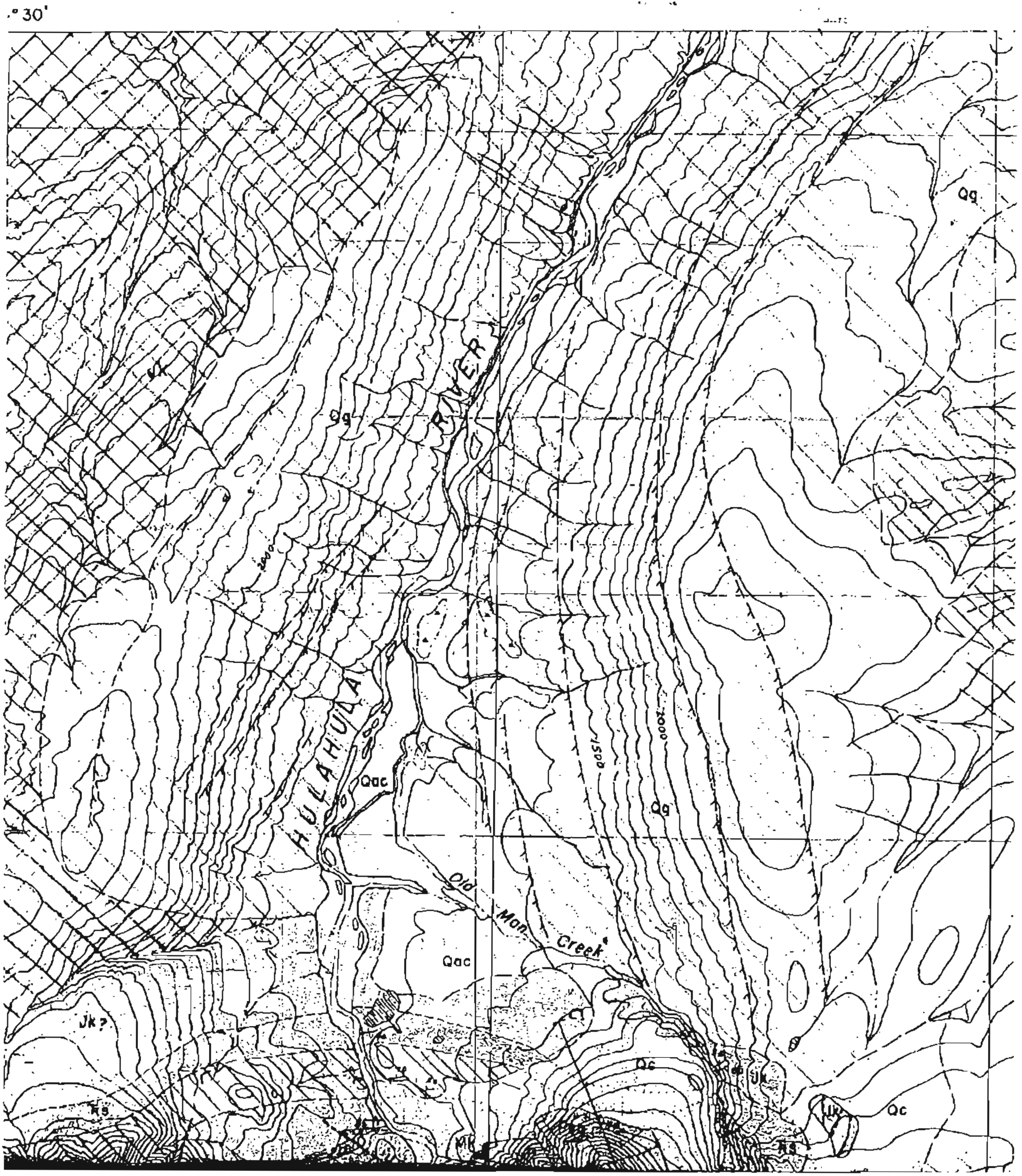
TRIASSIC

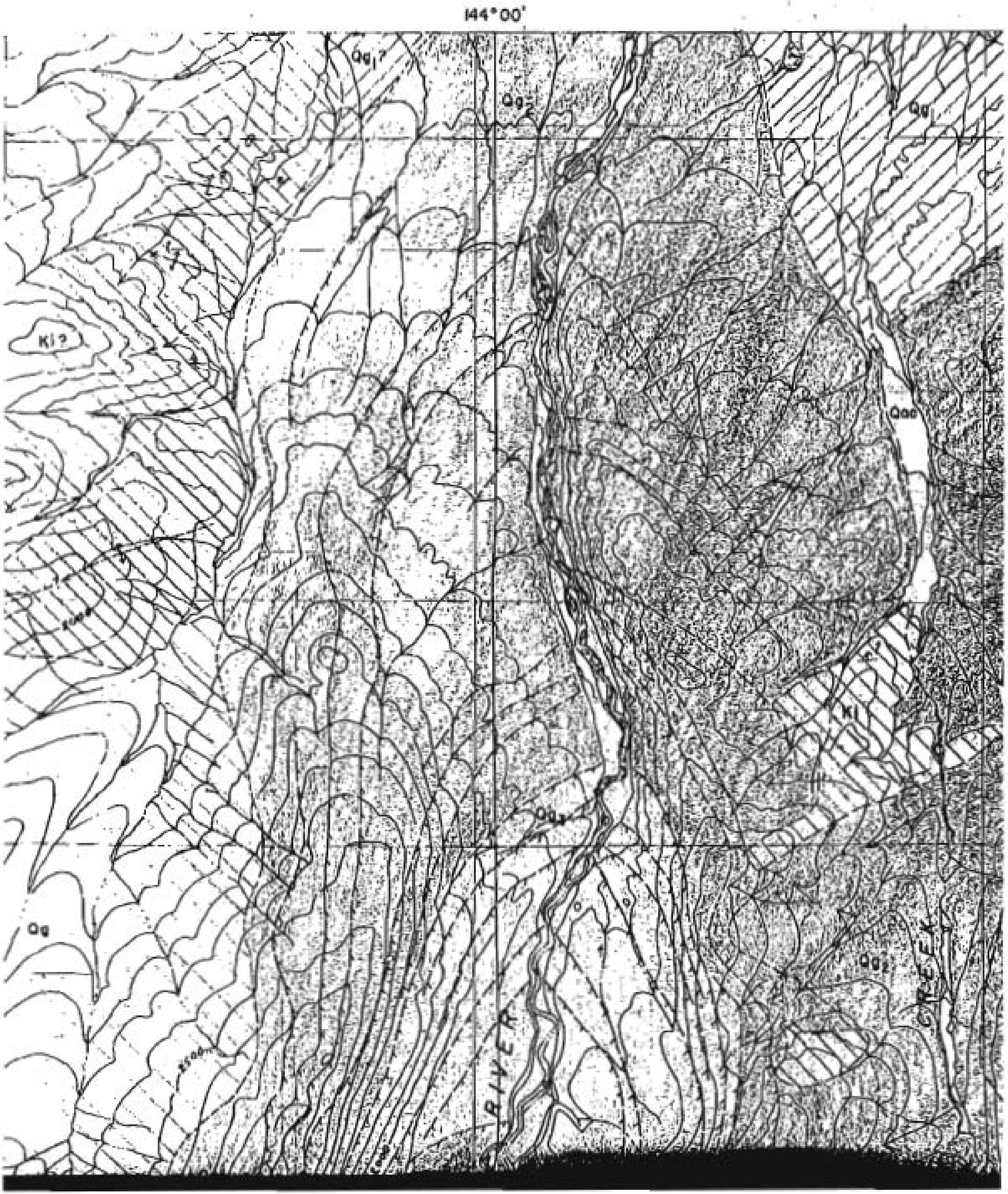
Rs

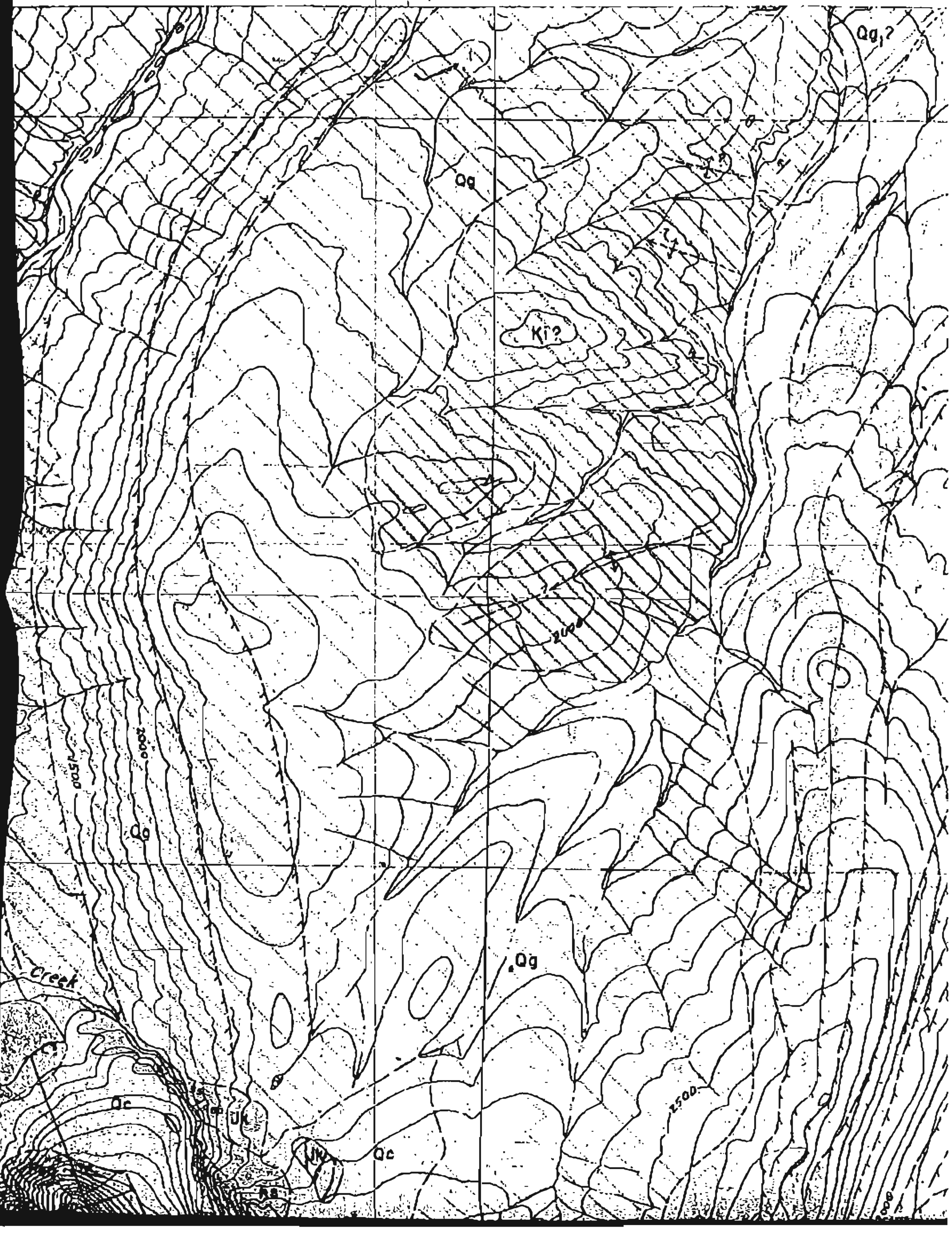
Pss

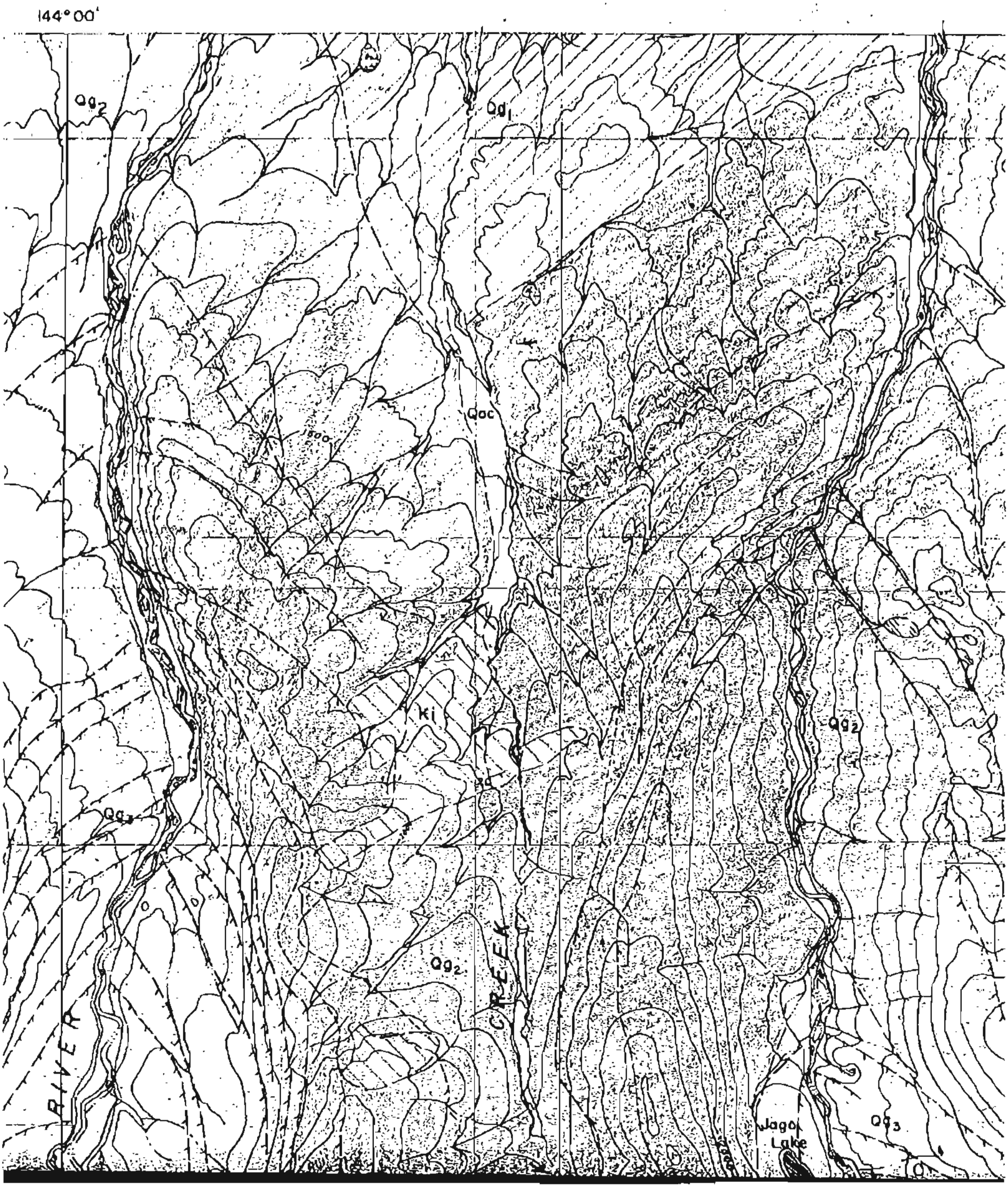
PE

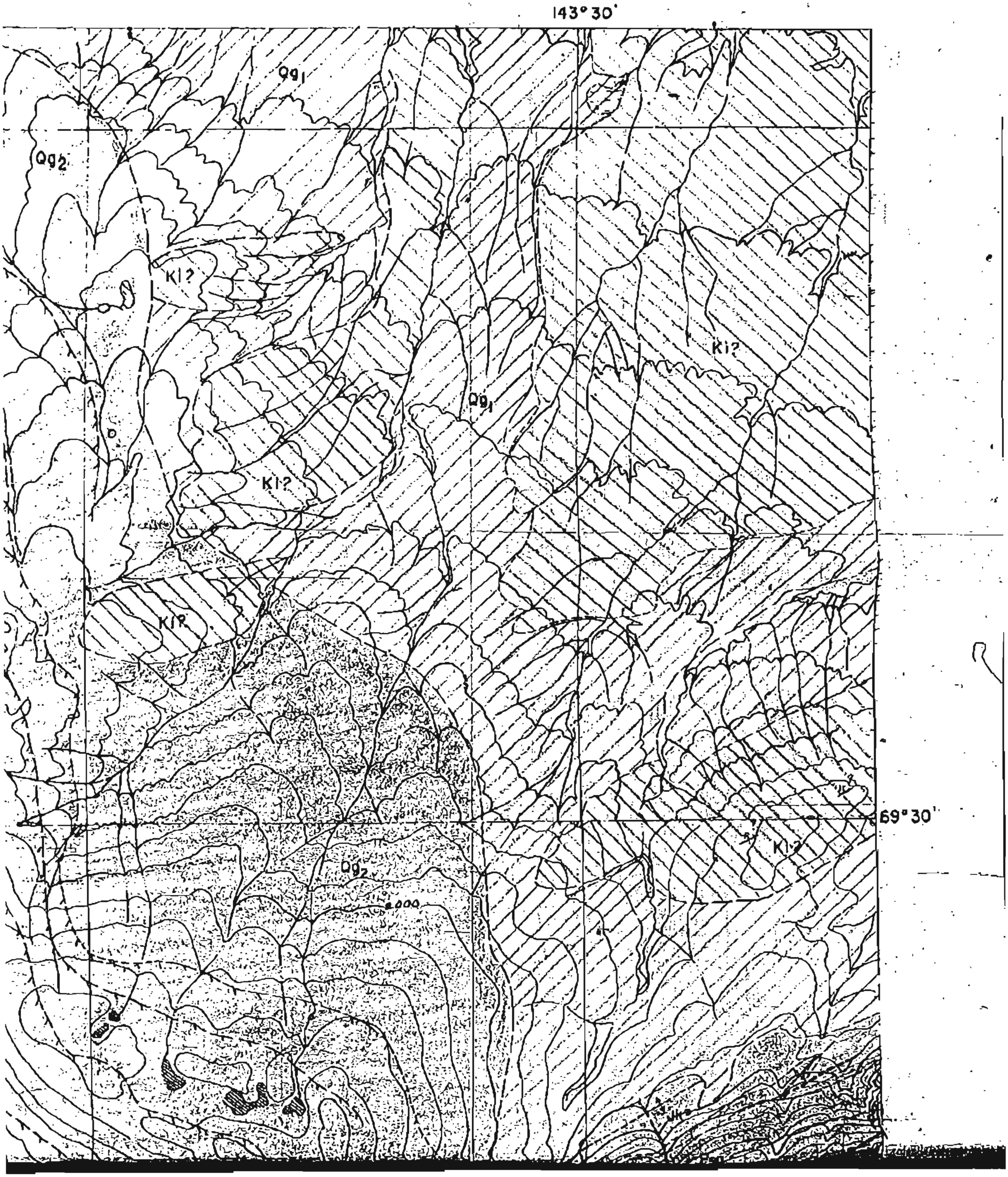


° 30'
Qg
Jk
Qg
HULAHULA RIVER
2000
Qac
Old Man Creek
2250
2000
Qg
Qac
Jk?
Qc
Jk
Rs
Qc
Rs


144°00'
Qg1?
Qg2?
Qg1
Kl?
Qac
Kl
Qg2
Qg2
Qg
2500
RIVER
CREEK


Qg1?
Qg
Ki?
2000
2000
2500
Qg
Creek
Qg
Qc
JK
JK
Qc
2500


144°00'
Qg2
Qd1
Qoc
1500
Ki
Qg3
Qg2
Qg2
CREEK
RIVER
Jago Lake
Qg3


143° 30'
69° 30'
Qg1
Qg2
Kl?
Kl?
Kl?
Qg1
Kl?
Kl?
Qg2
2000

TRIASSIC

PERMIAN–PENNSYLVANIAN(?)

MISSISSIPPIAN

MISSISSIPPIAN–DEVONIAN(?)

Shublik Formation
(Limestone, shale, sandstone)

Sadlerochit Formation

quartzite member

Ps

Pss

shale member

ferruginous sandstone member

Lisburne Group undivided
(Wahoo(?) and Alapah Limestones)

Kayak(?) Shale and
Kekiktuk Conglomerate

Schistose rocks
(Kekiktuk Conglomerate and/or
Neruokpuk Formation equivalents)

Mafic and Granitic rocks

Mafic rocks
(Includes volcanic(?) rocks
along Hulahula River and dikes)

rg

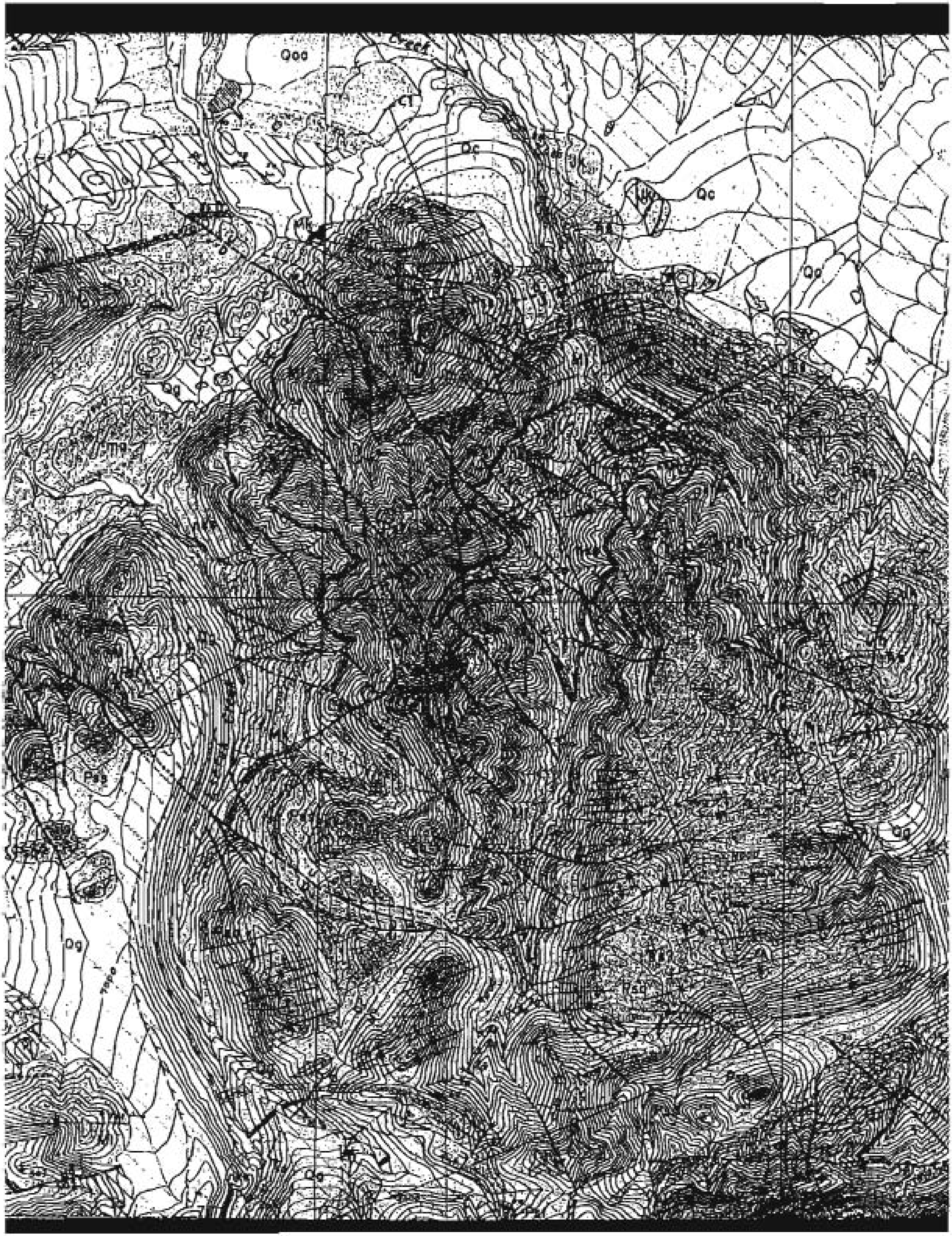
Romanzof granite
(quartz monzonite and granite;
rgp, porphyritic facies;
rgv, variable facies;
rgc, coarse facies)

Quartz monzonite dikes
Age relative to mafic
rocks uncertain)

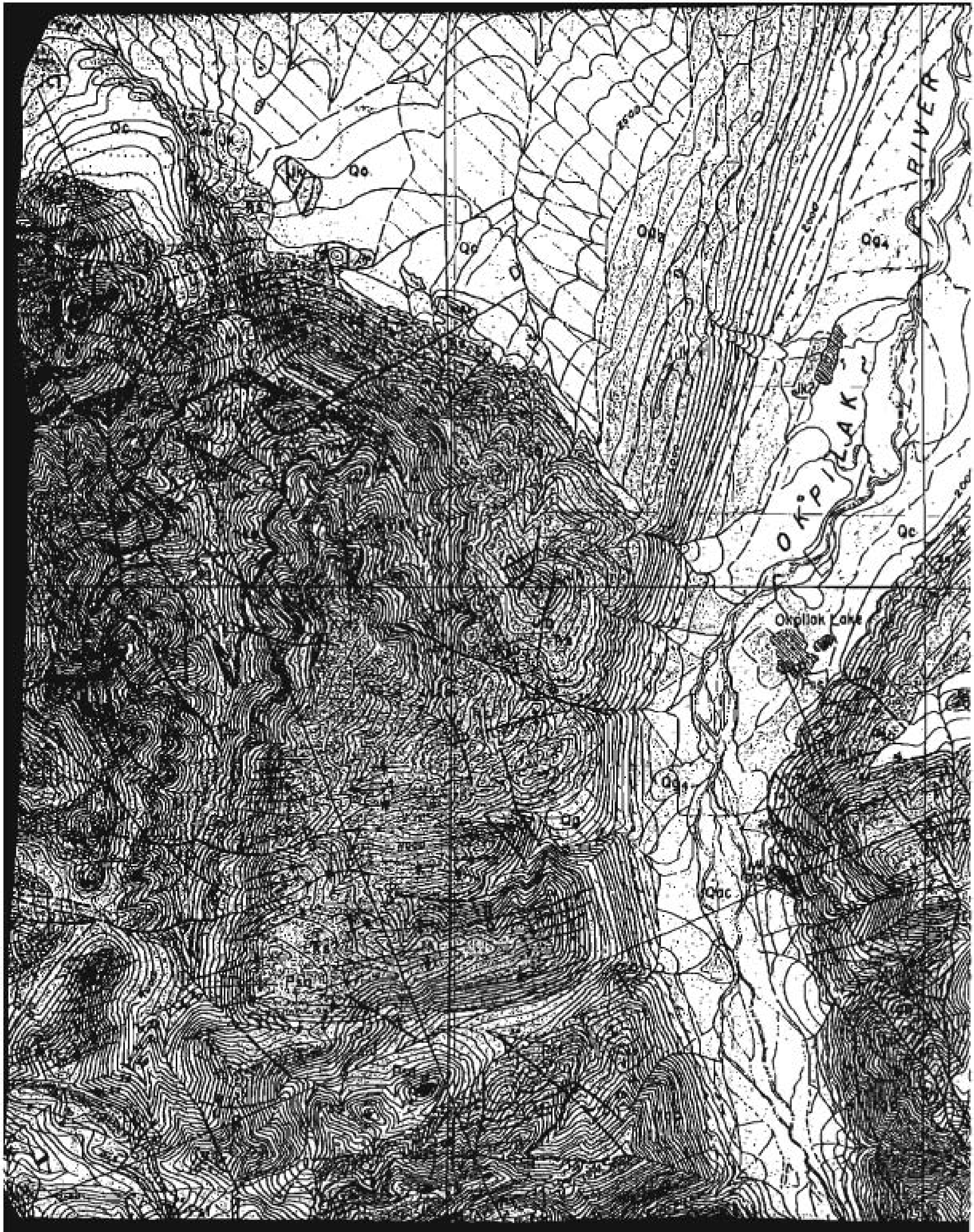
Miscellaneous units

Zone or area of sulfide
enrichment and silicification

Contact metamorphic and
metasomatic rocks
(Tactite and hornfels)

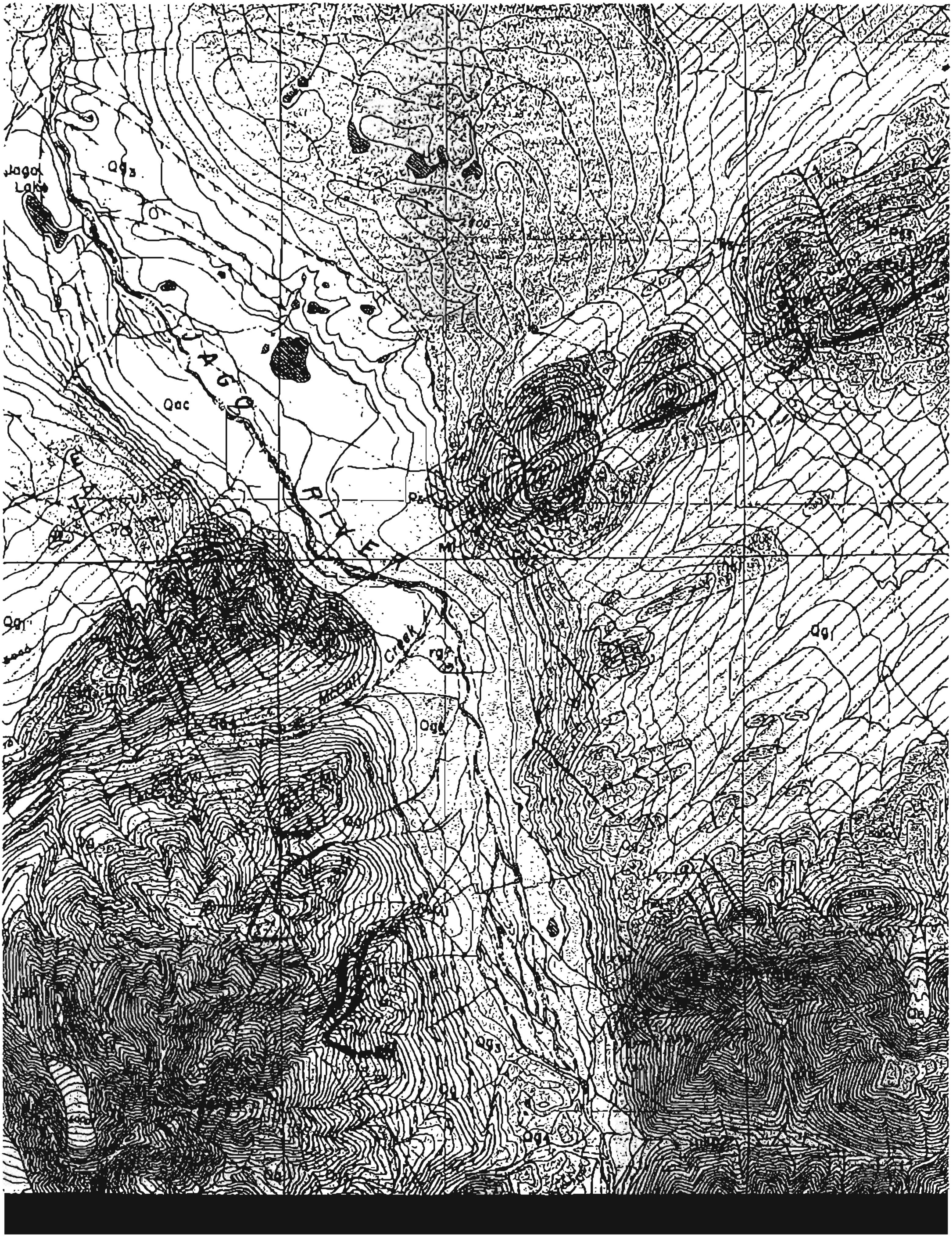

Qoa
Creek
Qc
Qc
Qg
Qg
Pas
Qg
Qg


OKPILAK
RIVER
Okpilak Lake
Qc
Qg



Qc
Qo
Qo
Qg
Qg4
OKPILAK
RIVER
Qc
Okpilak Lake
Qg4
Qo
Qac
Psa


VER
Qg2
CREE
OKPIROURAK
Jago Lake
Qg3
JAGO
Qac
Qac
Qg1
2000
Jk
Jk
Qg1
Qo
Psq
Qg1
Qg3
Qg


Jago Lake
Qg3
Qac
JAGO RIVER
Qg1
Creek
rg
Qg3
Qg1
Qg1
Qg3
Qg1

Romanzof granite
(quartz monzonite and granite;
rgp, porphyritic facies;
rgv, variable facies;
rgc, coarse facies)

Quartz monzonite dikes
(Age relative to mafic
rocks uncertain)

Miscellaneous units

Zone or area of sulfide
enrichment and silicification

Contact metamorphic and
metasomatic rocks
(Tactite and hornfels)

Jago River

nkq
nkp
nkb
nkl

nkq, quartzite unit
(position relative to
other units uncertain)
nkp, phyllite-chert
limestone unit
nkb, brown-weathering
quartzite unit
nkl, limestone unit

DEVONIAN (?)

nk

Neruokpuk Formation undivided
(Dominant lithologies indicated
on map in some portions of area)

Esetuk Glacier

(Relative positions
of units uncertain)

nksl
nks
nkpq

nksl, sandy limestone unit
nks, silicified carbonate unit
nkpq, phyllite-quartzite unit

Old Man Creek and Hulahula River

nks
nkpq

nks, silicified carbonate unit
nkpq, phyllite-quartzite unit

Contact
(Dashed where approximate,
short dashed where inferred,

45

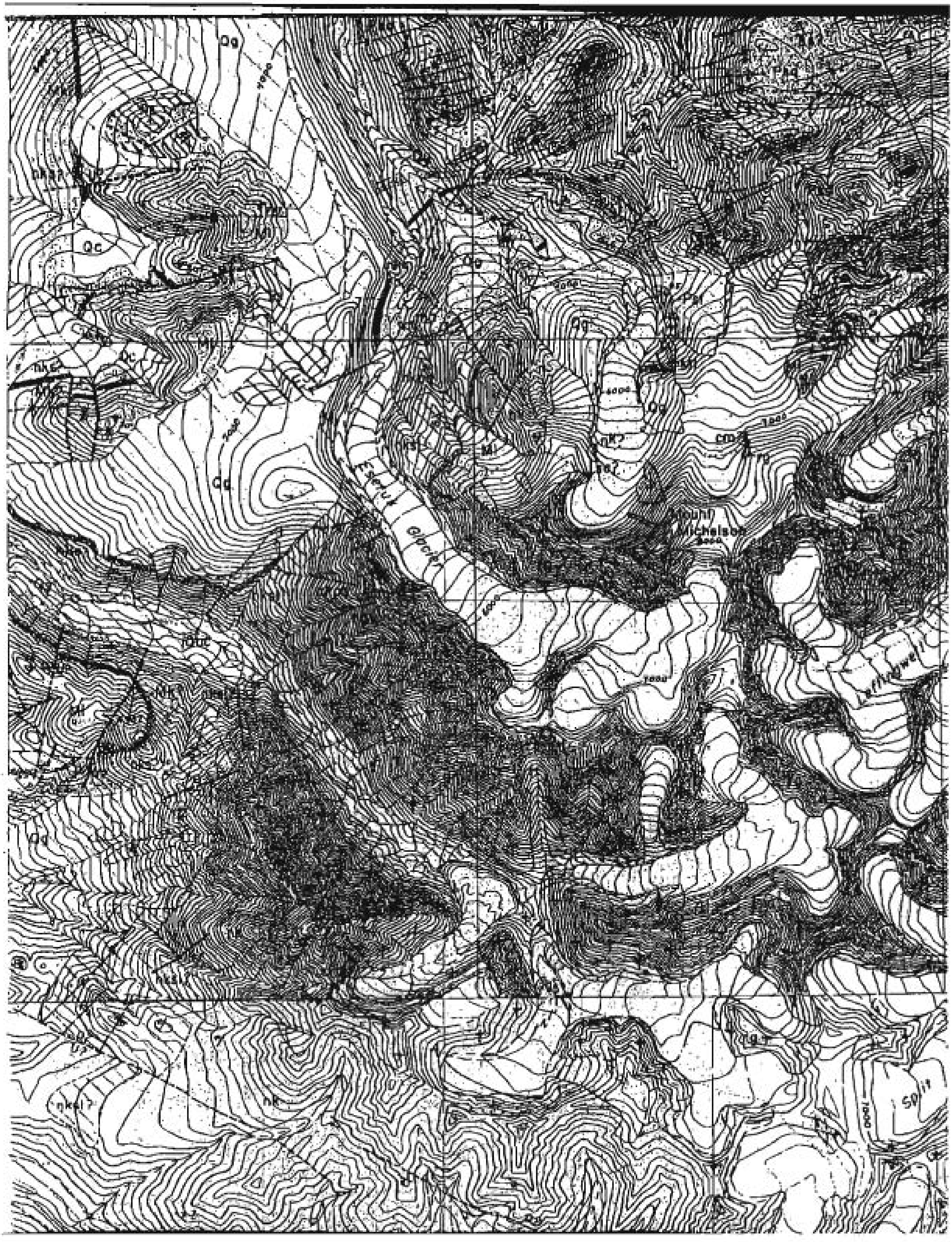
Strike and dip of beds
(Includes generalized strike
and dip component of moderately
contorted beds)

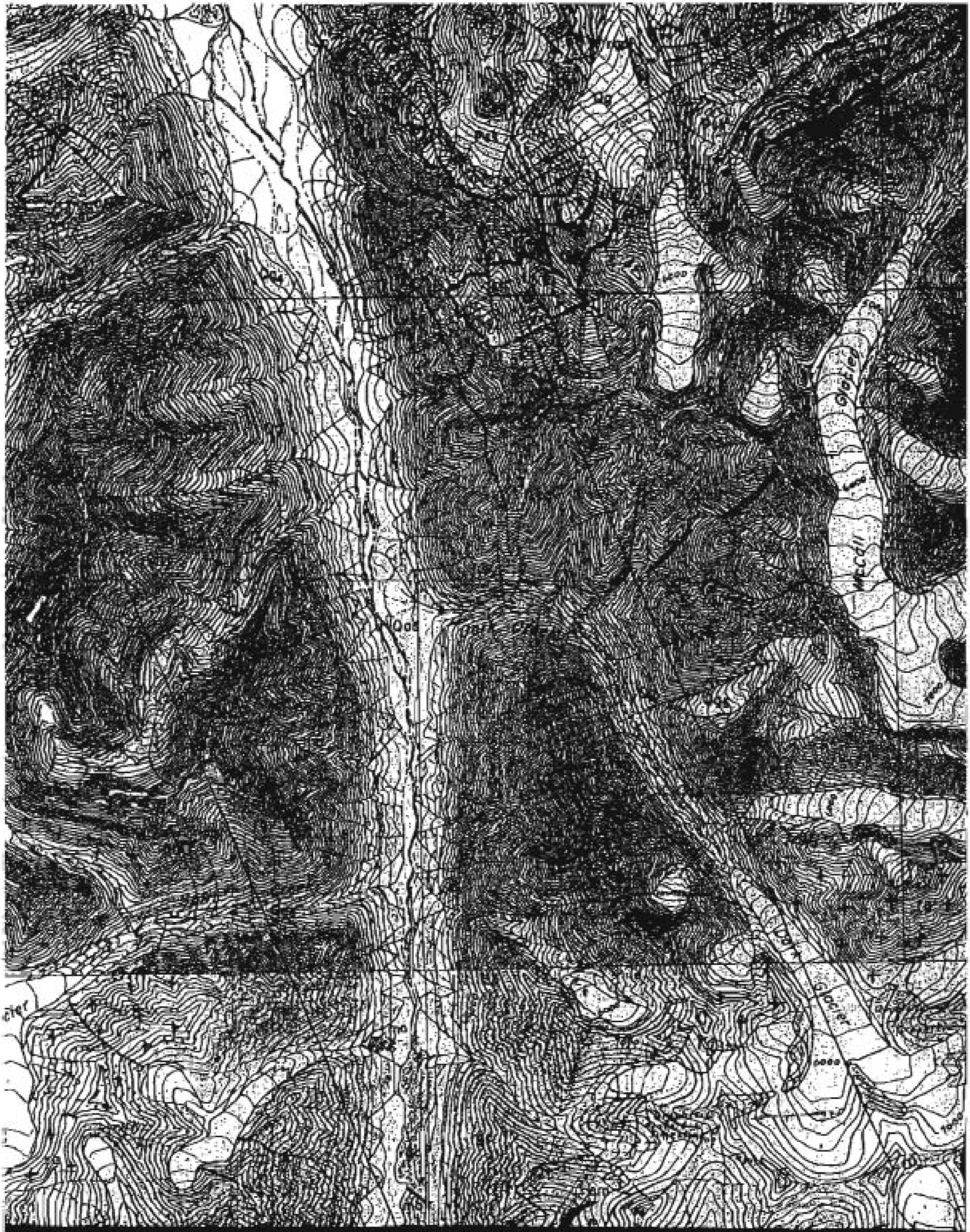
U
D

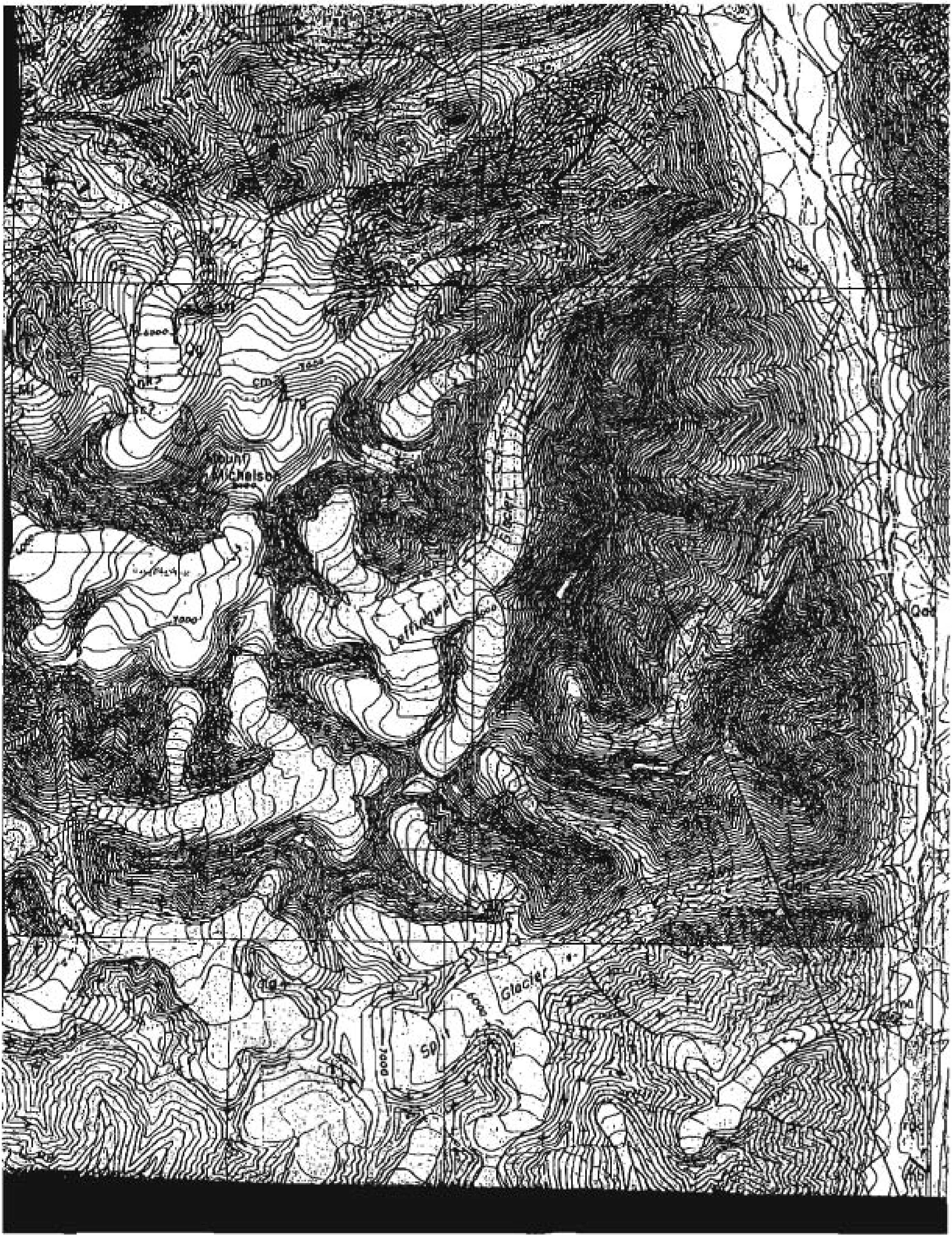
Fault
(Dashed where approximate,
short dashed where inferred,
where concealed

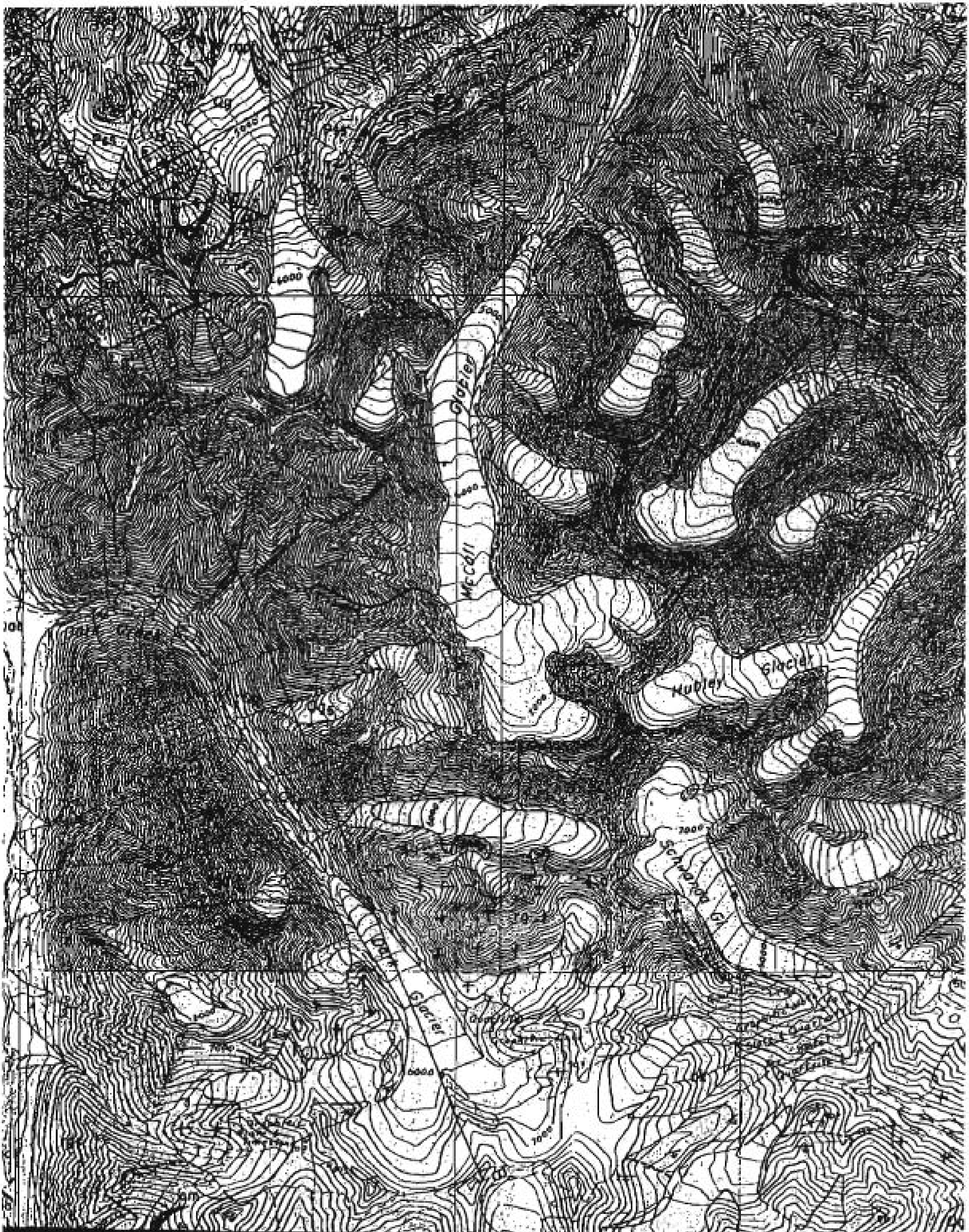
50

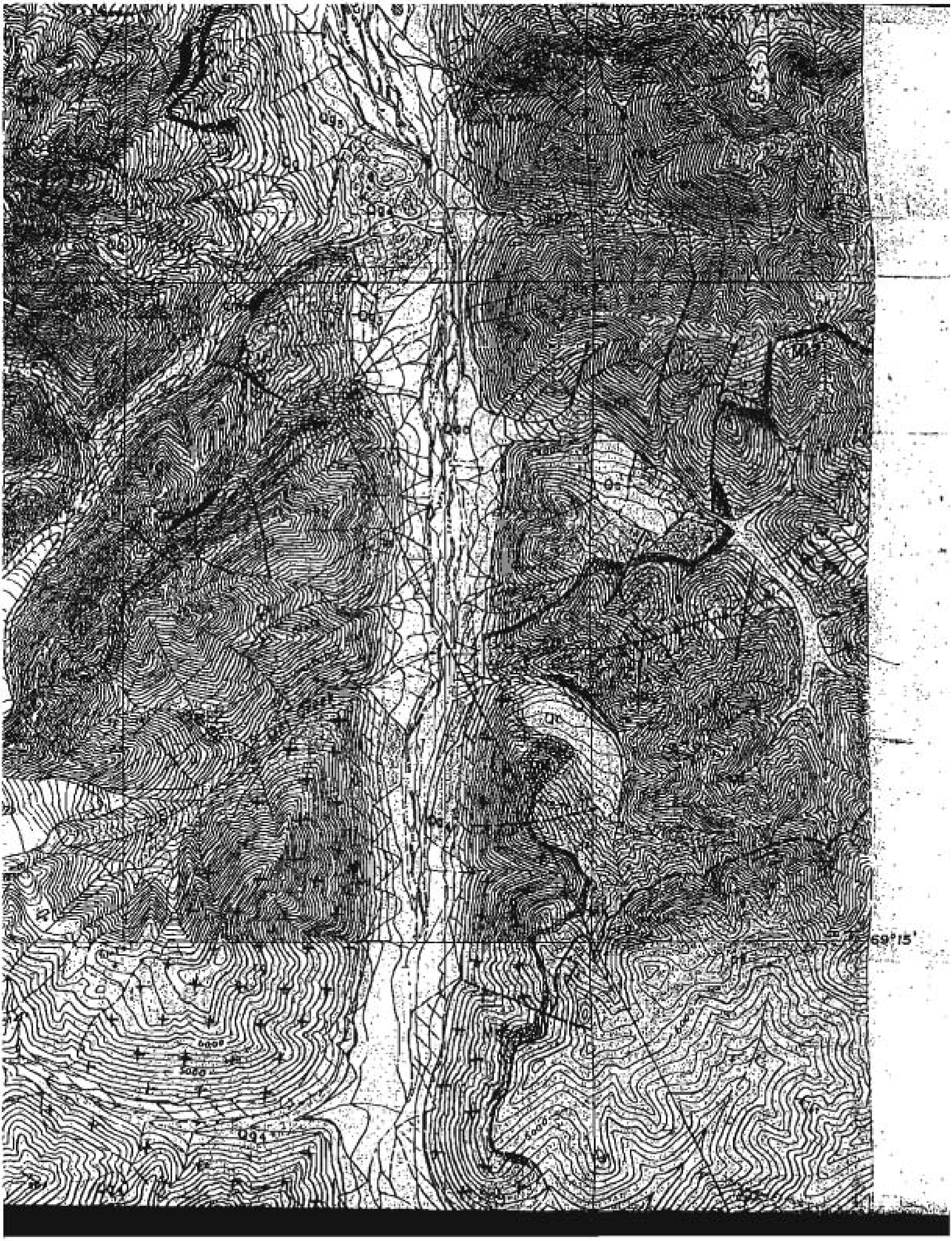
Strike and dip of beds
(Based on photo-interpretation
and binocular reconnaissance)


Qg
Qc
Mi
nK?
Esetuk Glacier
Mount Michelson
Qg
nK?
nkcl?
nK
Spl?


Qal
Glacier


Mount Michelson
Leffingwell
Glacier
Sp
cm
7000
8000
Qal


McCall Glacier
Hubley Glacier
Schwanda Gl.
Glacier
6000
7000


69°15'

nkpq, phyllite-quartzite unit

Contact
(Dashed where approximate,
short dashed where inferred,

U
D
Fault
(Dashed where approximate,
short dashed where inferred,
dotted where concealed,
U, upthrown side,
D, downthrown side)

Thrust fault
(T on upper plate)

Anticline, showing trace of
axial plane and plunge of axis
(Dashed where approximate,
short dashed where inferred)

Syncline, showing trace of
axial plane and plunge of axis
(Dashed where approximate,
short dashed where inferred)

Overturned or recumbent
anticline

Overturned or recumbent
syncline

FA
Fold axes, showing trace
of axial planes

45
Strike and dip of beds
(Includes generalized strike
and dip component of moderately
contorted beds)

50
Strike and dip of beds
(Based on photo-interpretation
and binocular reconnaissance)

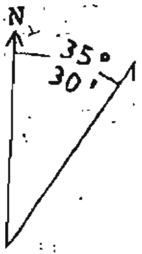
35
Strike and dip of
overturned beds

90
Strike of vertical beds

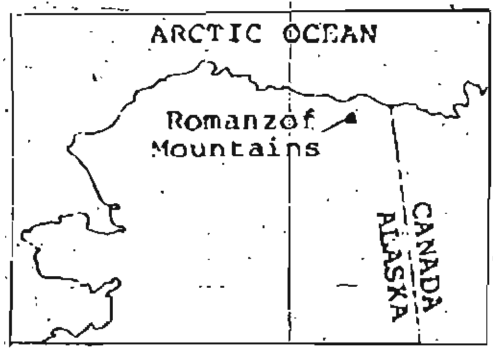
75
Generalized strike and dip
of highly contorted beds

⊕
Horizontal beds

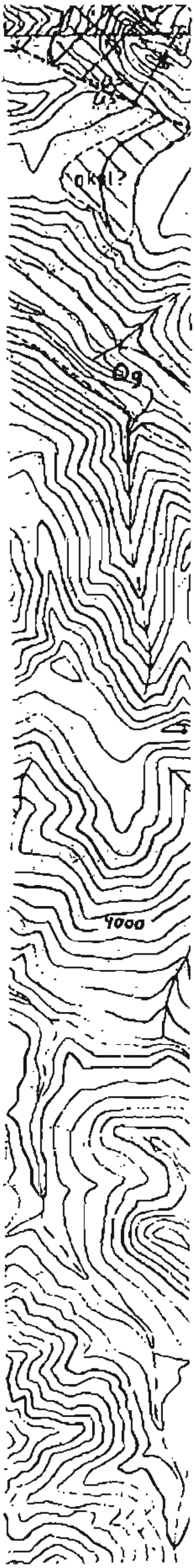
D D'
Line of cross section



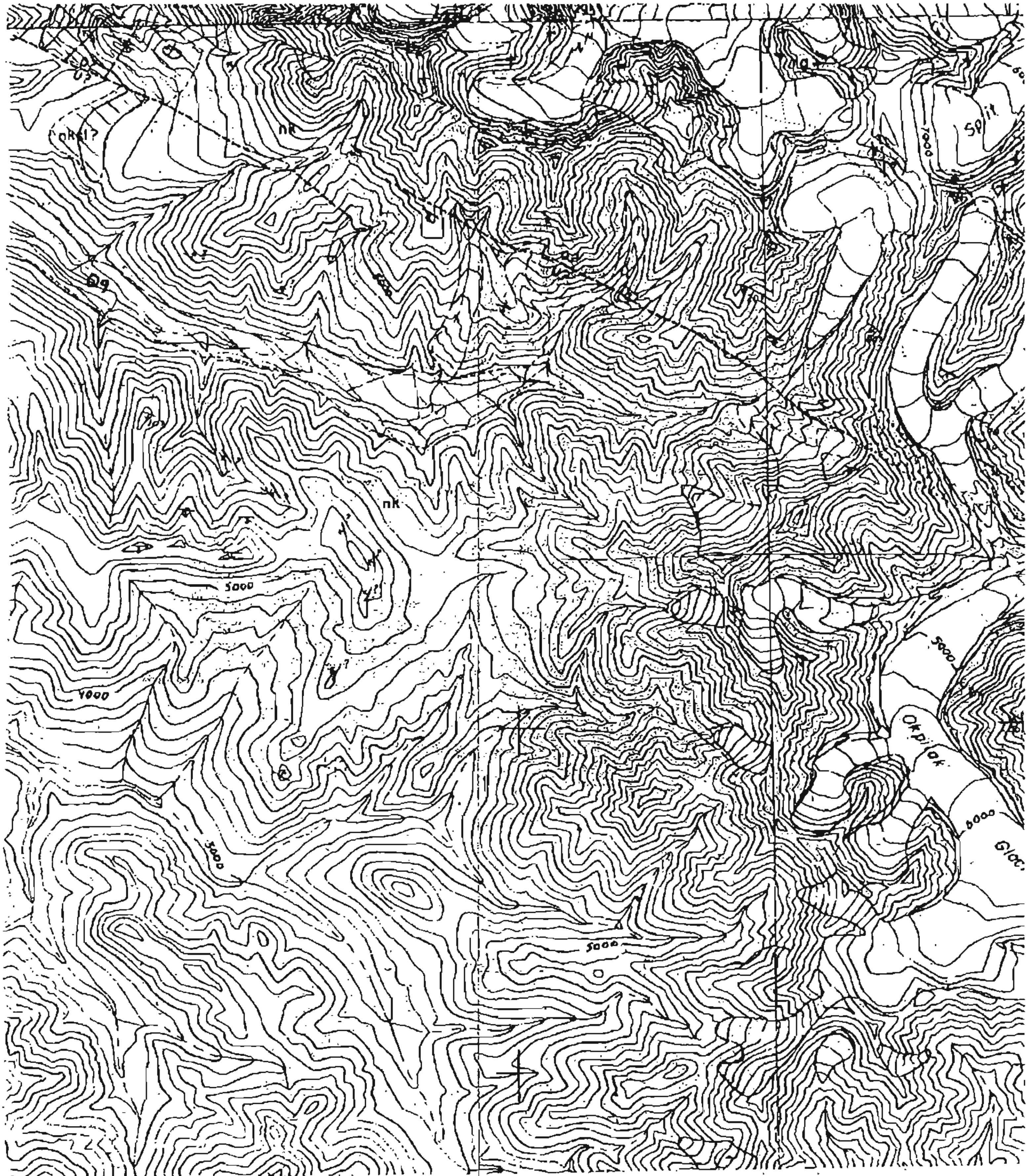
Magnetic declination
1951



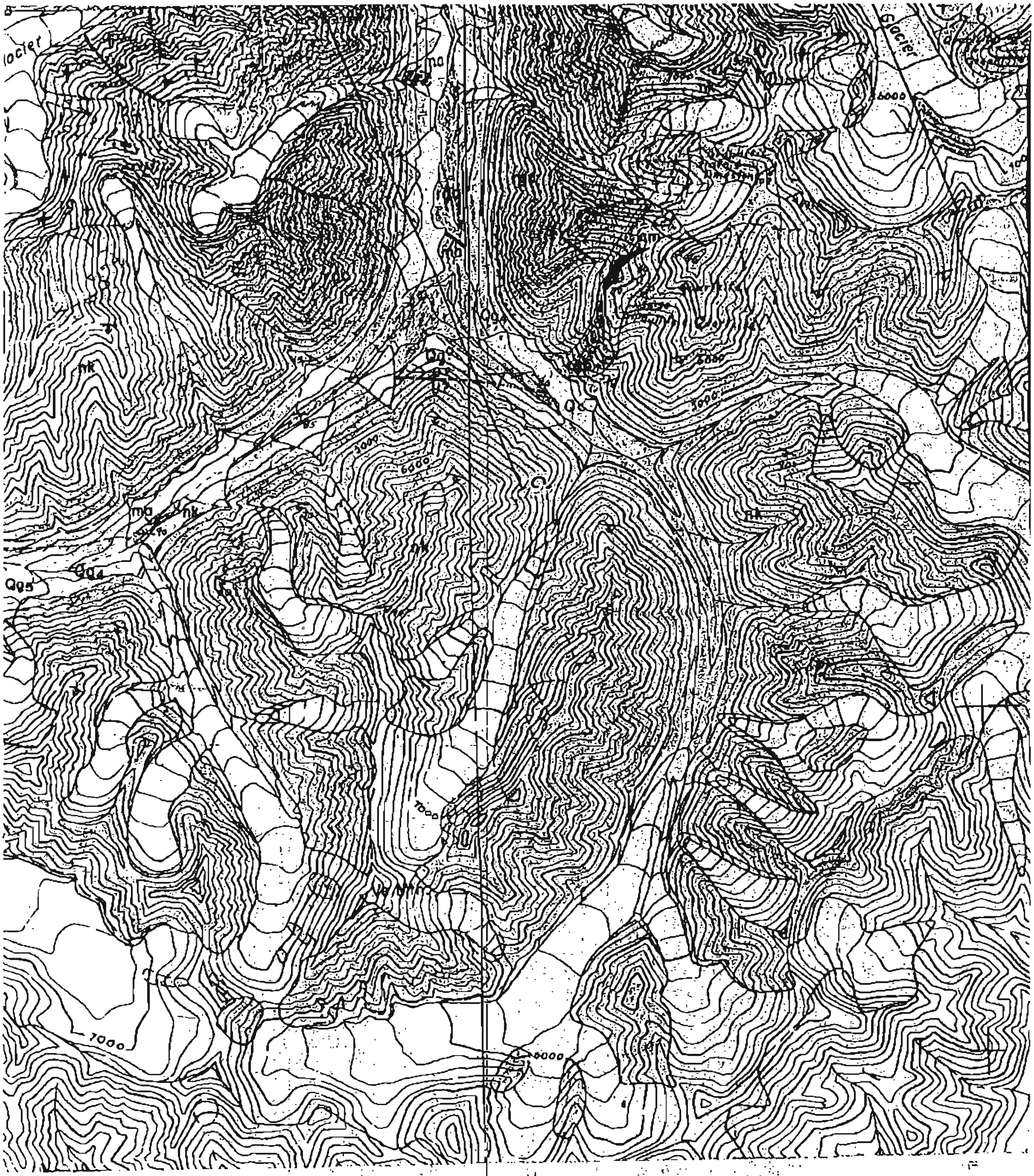
INDEX MAP



Base com



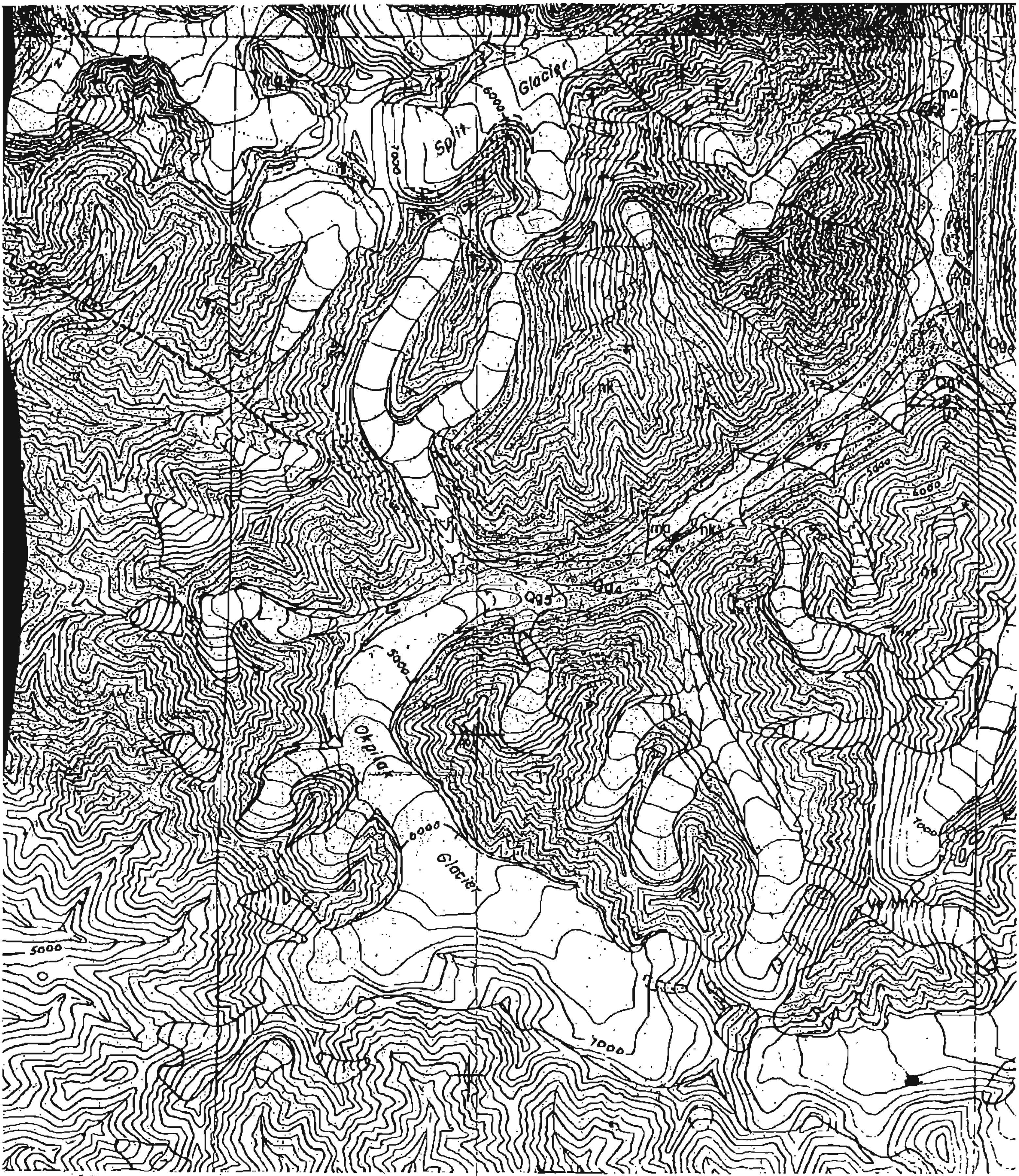
Base compiled by U.-S. Geological Survey



GEOLOGIC MAP OF THE ROMANZOF MOUNTAINS, ALASKA

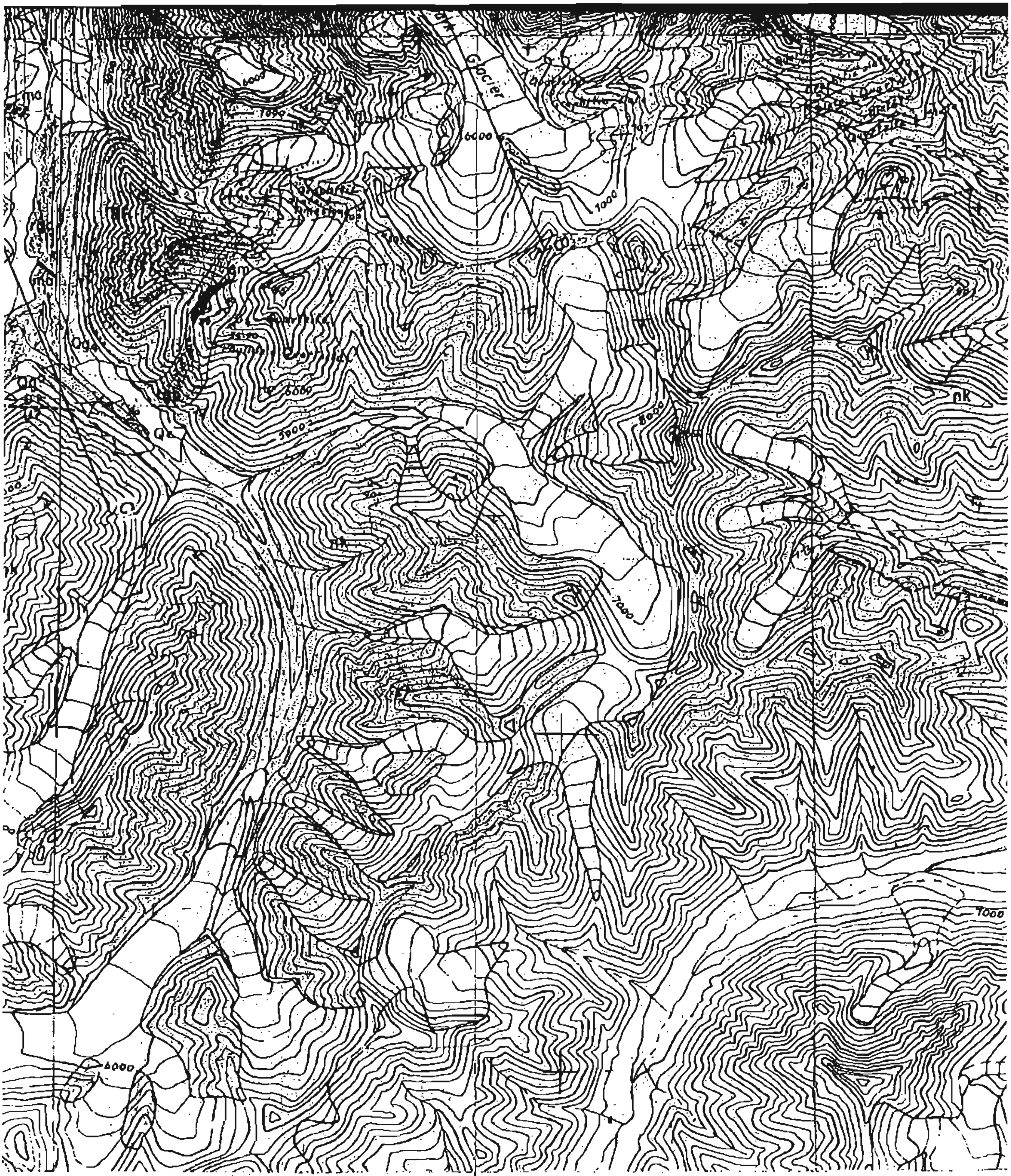
Scale 1:63,360

0 1 2 3 4 5 Miles



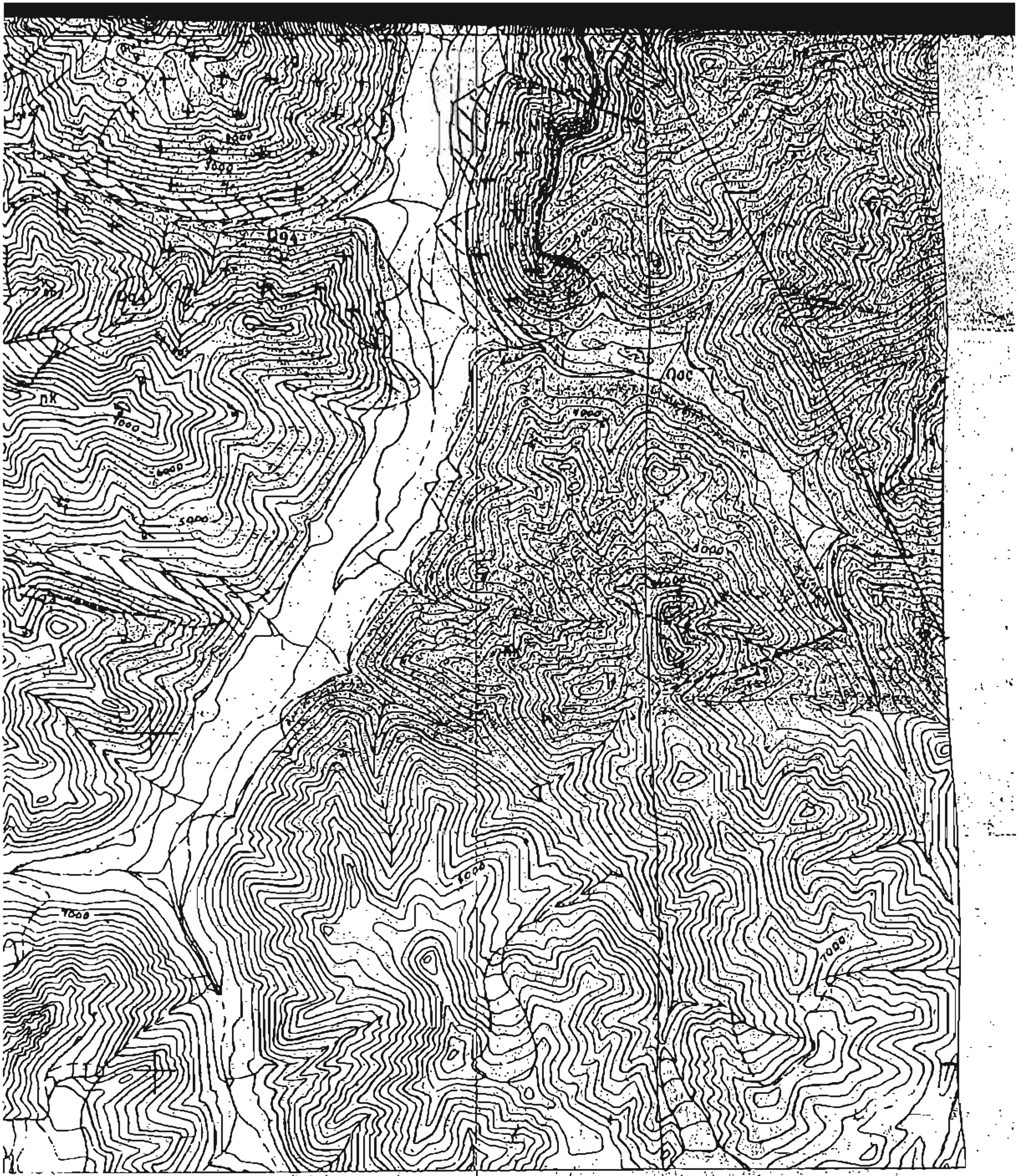
GEOLOGIC MAP OF THE ROMANZ

Scale 1:63,3



OMANZOF MOUNTAINS, ALASKA

ale 1:63,360



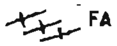
Geology by E. G. Sable, R. S. Bunnell,
and G. R. Kunkle, 1957-1958
Geology west of Hulahula River by
C. L. Whittington, E. G. Sable,
and A. H. Lachenbruch, 1948

axial plane and plunge of axis
(Dashed where approximate,
short dashed where inferred)

Syncline, showing trace of
axial plane and plunge of axis
(Dashed where approximate,
short dashed where inferred)

Overturned or recumbent
anticline

Overturned or recumbent
syncline

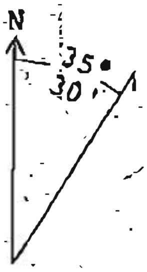


Fold axes, showing trace
of axial planes

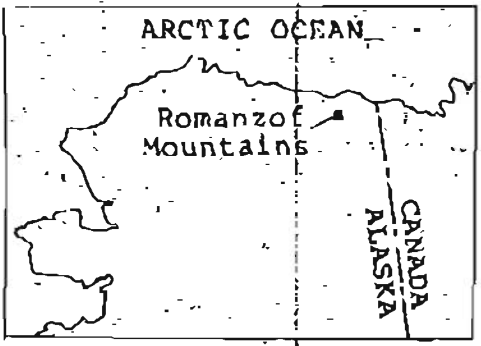
Generalized strike and dip
of highly contorted beds

Horizontal beds

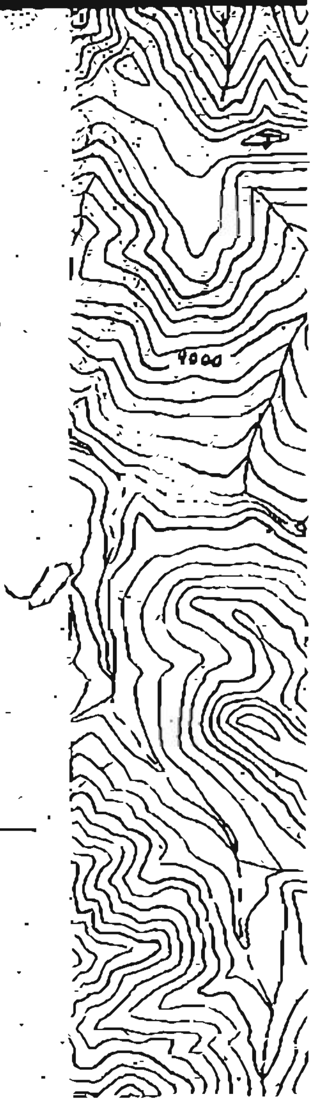
Line of cross section



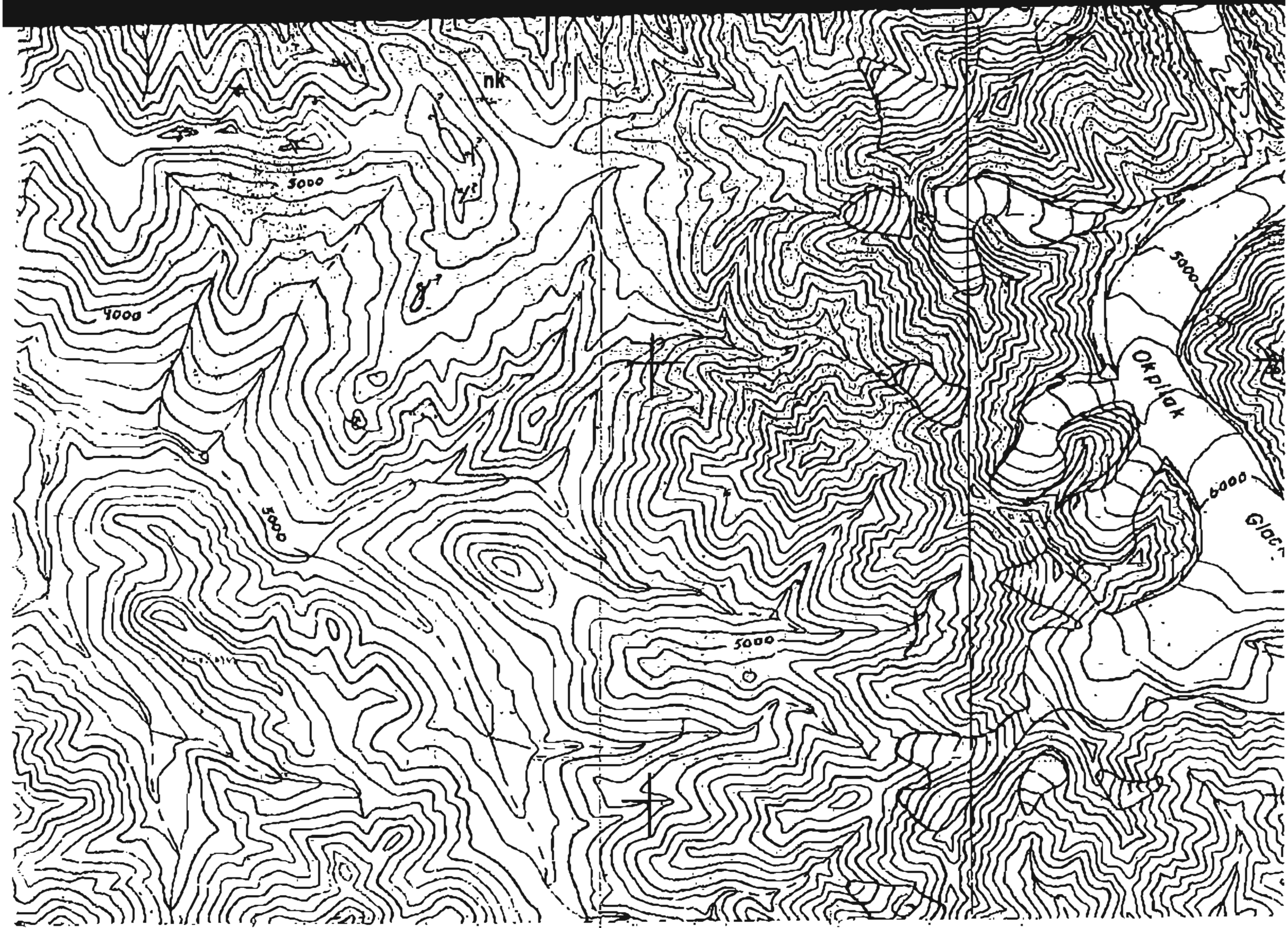
Magnetic declination
1951



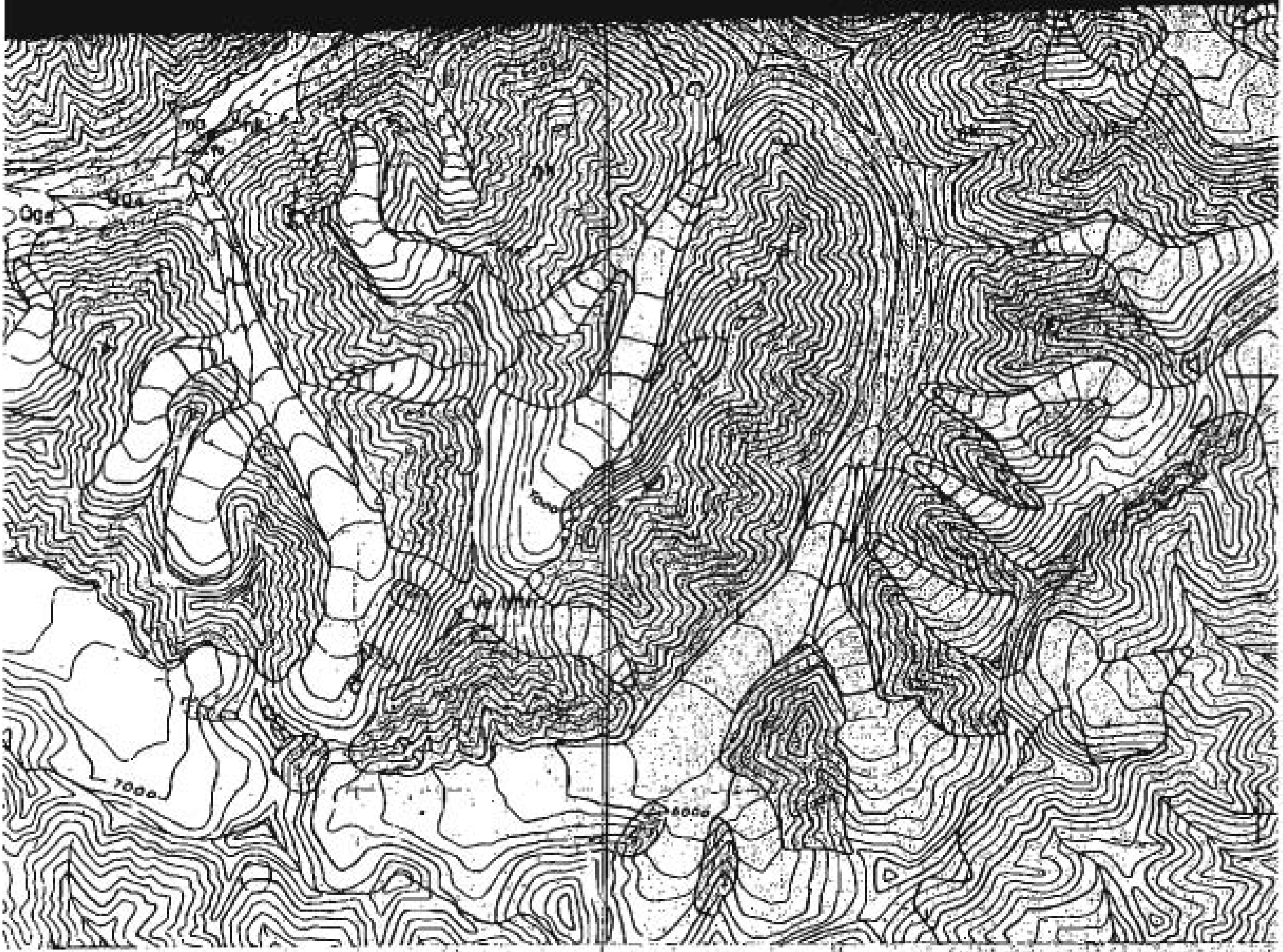
INDEX MAP



Base compi



Base compiled by U. S. Geological Survey

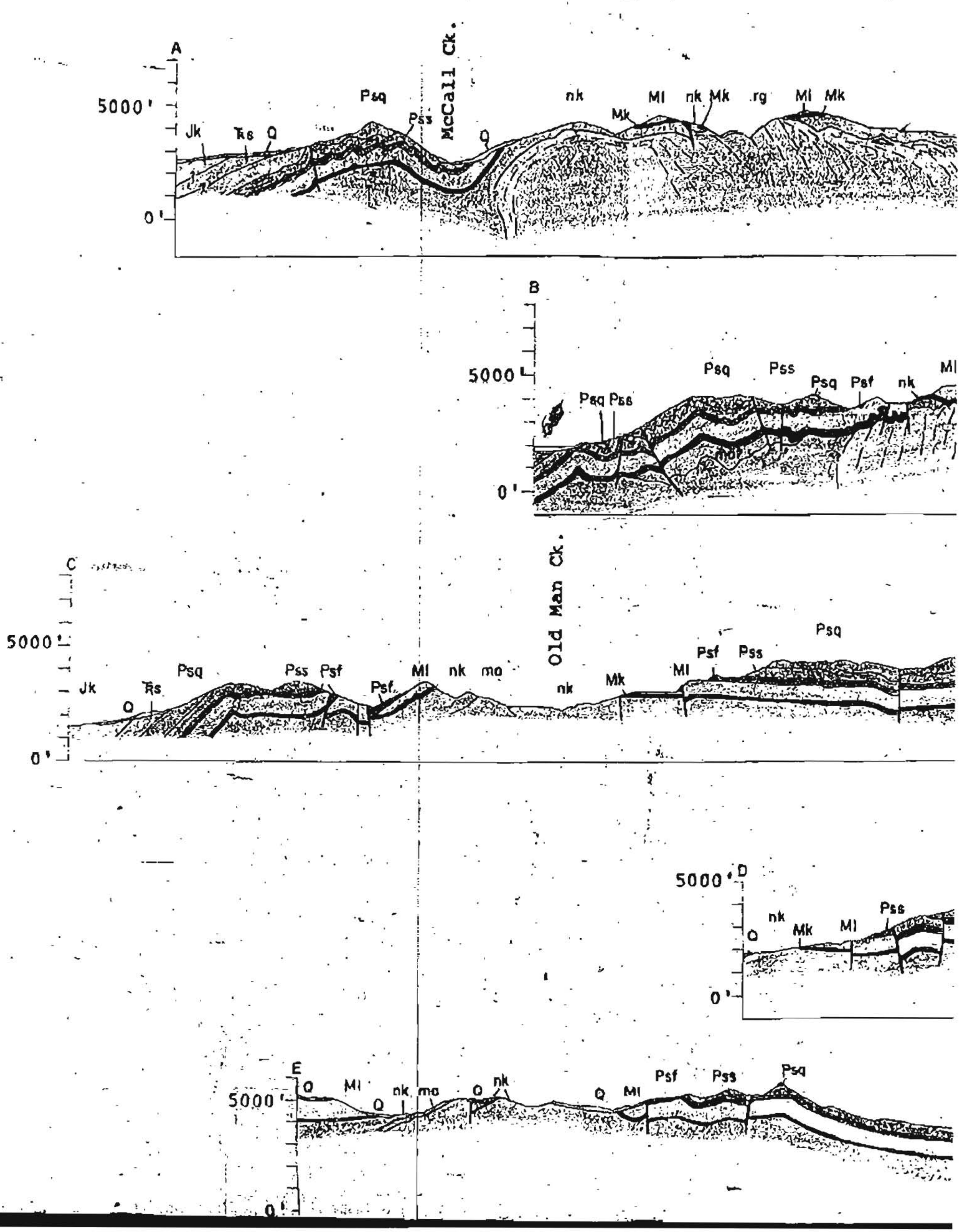


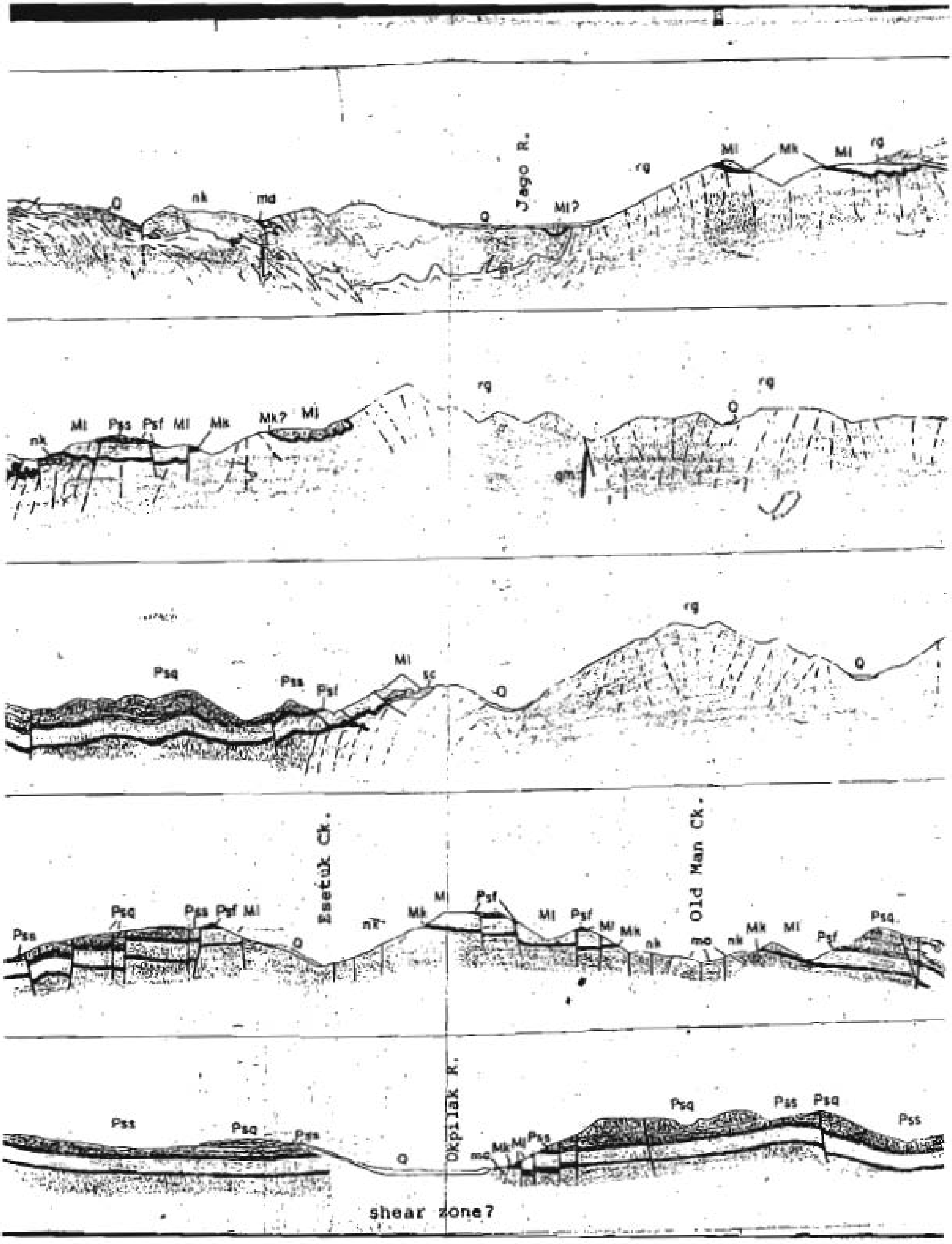
GEOLOGIC MAP OF THE ROMANZOF MOUNTAINS, ALASKA

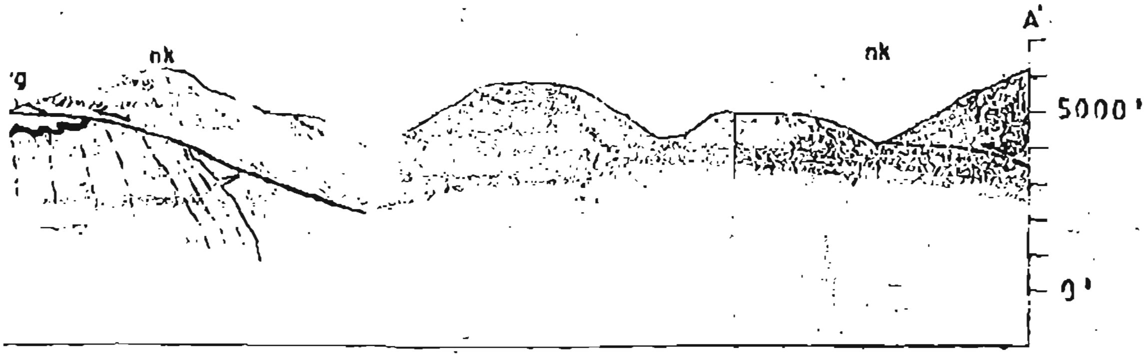
Scale 1:63,360

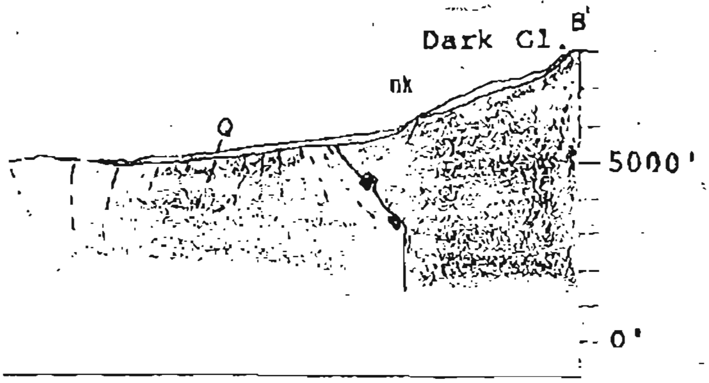
0 1 2 3 4 5 Miles

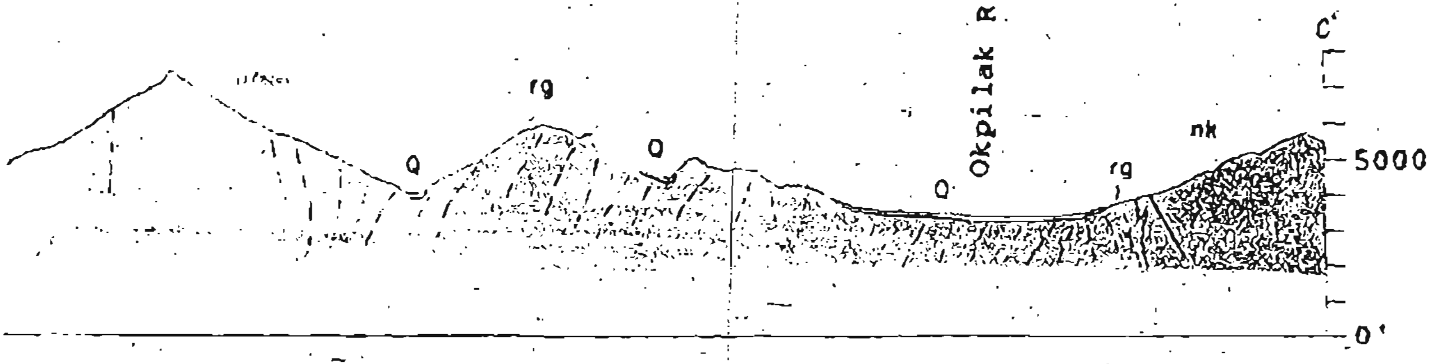
Contour interval 100 and 200 feet

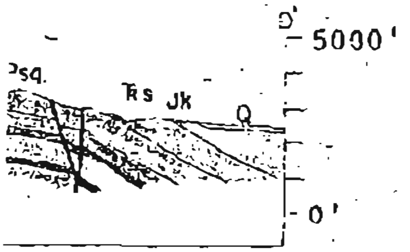

A
5000'
0'
Jk
Ŧs
Q
Psq
Pss
McCall Ck.
Q
nk
Mk
Ml
nk
Mk
rg
Ml
Mk
B
5000'
0'
Psq
Pss
Psq
Pss
Psq
Psf
nk
Ml
Old Man Ck.
C
5000'
0'
Jk
Q
Ŧs
Psq
Pss
Psf
Psf
Ml
nk
mo
nk
Mk
Ml
Psf
Pss
Psq
D
5000'
0'
Q
nk
Mk
Ml
Pss
E
5000'
0'
Q
Ml
Q
nk
mo
Q
nk
Q
Ml
Psf
Pss
Psq

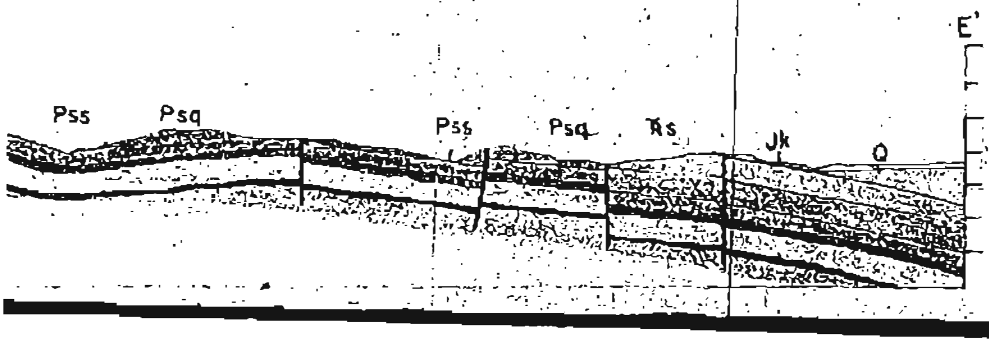

Q
nk
md
Jago R.
Q
Ml?
rg
Ml
Mk
Ml
rg
nk
Ml
Pss
Psf
Ml
Mk
Mk?
Ml
rg
rg
Q
gm
Psq
Pss
Psf
Ml
sc
Q
rg
Q
Pss
Psq
Pss
Psf
Ml
Q
Esetuk Ck.
nk
Mk
Ml
Psf
Ml
Psf
Ml
Mk
nk
Old Man Ck.
md
nk
Mk
Ml
Psf
Psq
Pss
Psq
Pss
Q
Okpilak R.
md
Mk
Ml
Pss
Psq
Pss
Psq
Pss
shear zone?







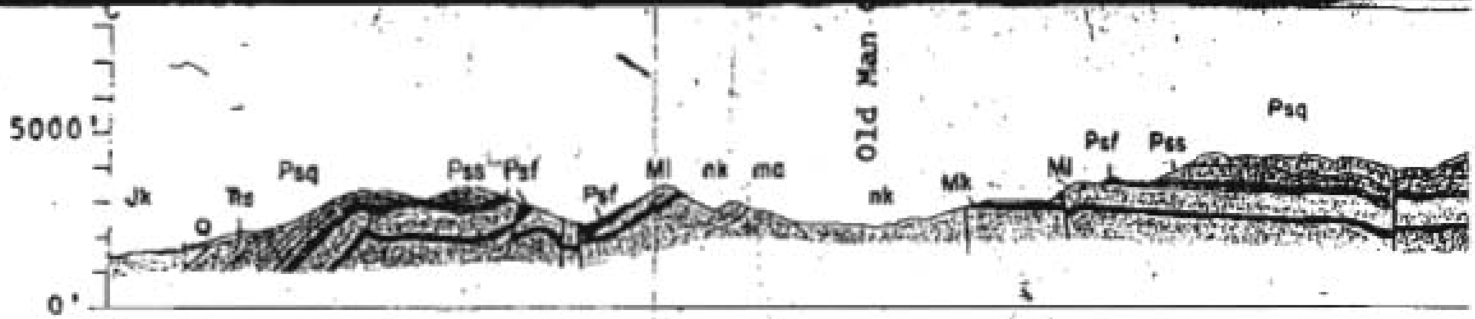


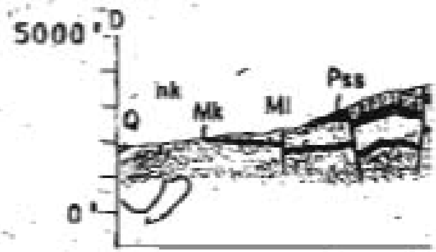


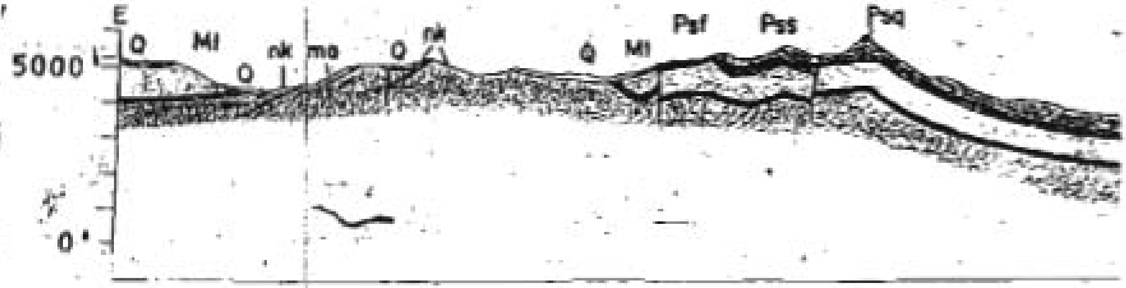
EXPLANATION

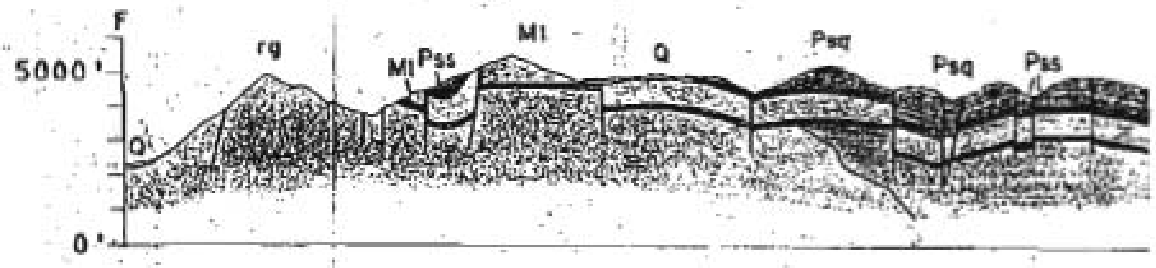
Q - glacial-alluvial
Jk - Kingak
Trs - Shublik
Psq }
Pss } - Sadlerochit
Psf }
Ml - Lisburne
Mk - Kayak(?)-Kekiktuk
sc - schist
ma - mafic rocks
qm - quartz-monzonite
ro - Romanzof granite
nk - Neruokpuk

——— thrust fault
– – – flow layers(?)
.... bedding


C
5000'
0'
Jk
Q
Ŧrs
Psq
Pss
Psf
Psf
Ml
nk
ma
Old Man
nk
Mk
Ml
Psf
Pss
Psq


D
5000'
0'
nk
Q
Mk
Ml
Pss


E
5000'
0'
Q
Ml
Q
nk
ma
Q
nk
Q
Ml
Psf
Pss
Psq


F
5000'
0'
Q
rg
Ml
Pss
Ml
Q
Psq
Psq
Pss

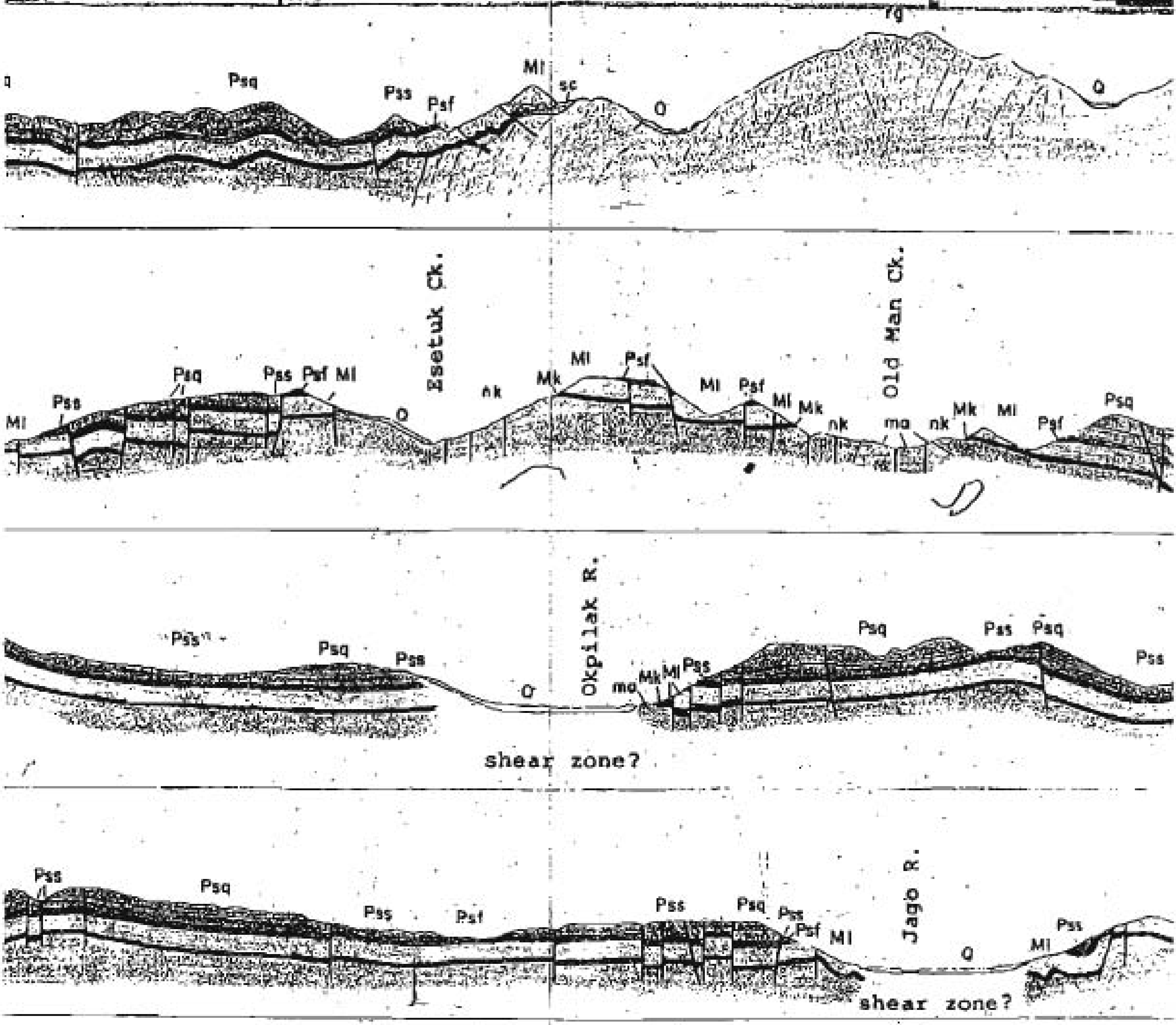
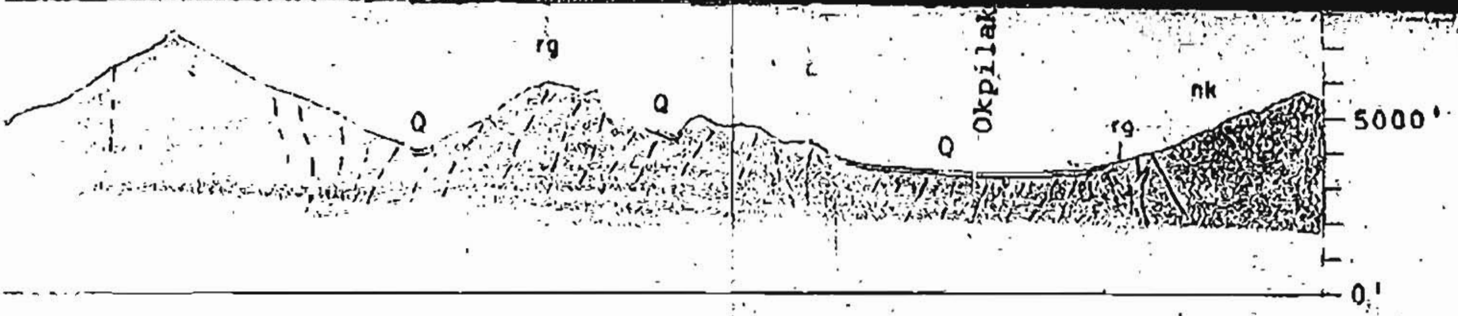
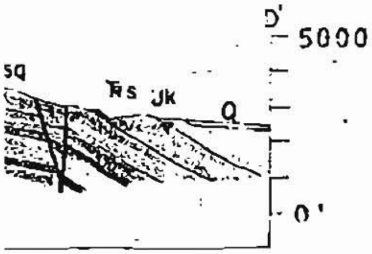


PLATE 2. STRUCTURE SECTIONS OF THE ROMANZOF MOUNTAINS, ALASKA

Scale 1:63,360

Datum is mean sea level

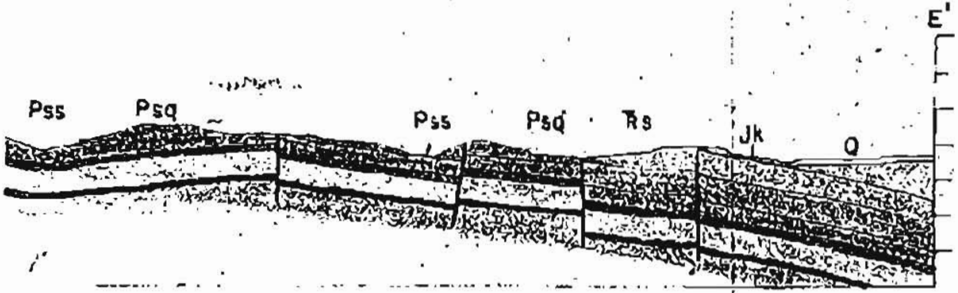


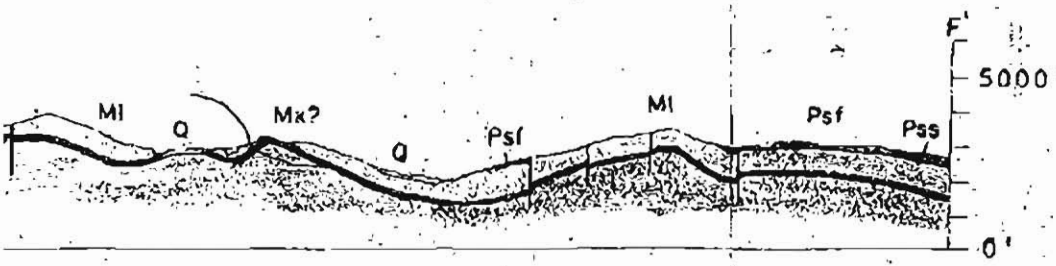


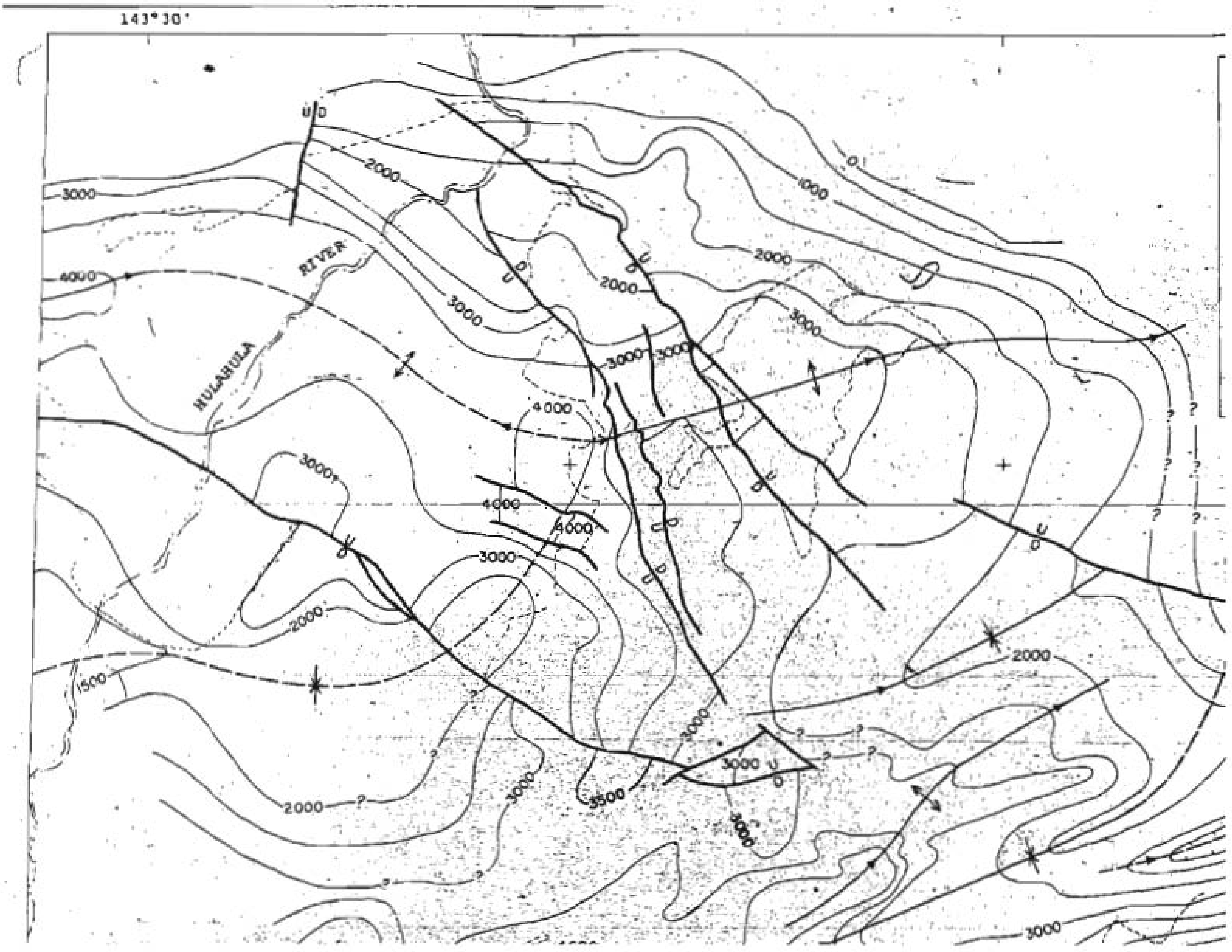
EXPLANATION

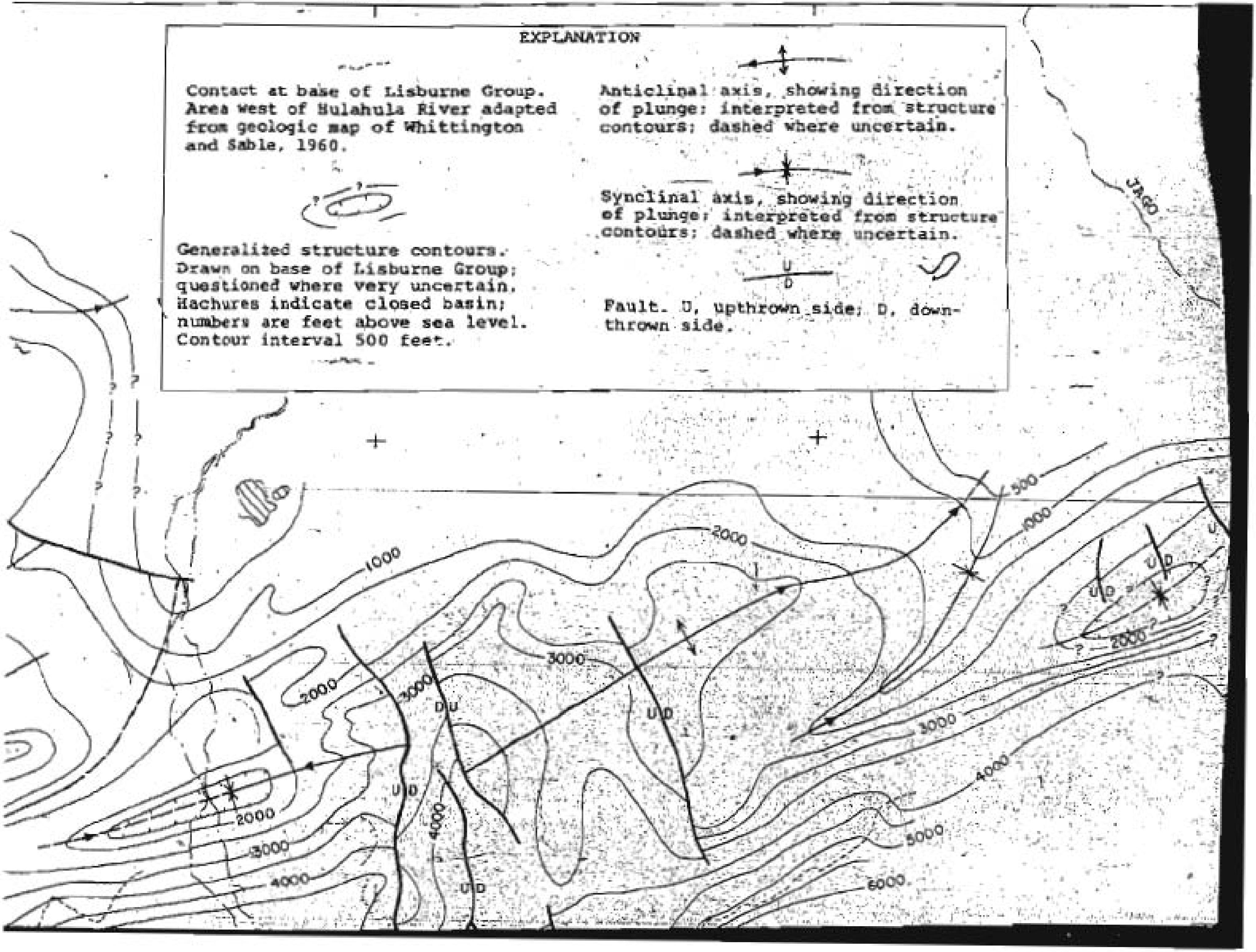
Q - glacial-alluvial
Jk - Kingak
TRs - Shublik
Psq }
Pss } - Sadlerochit
Psf }
Ml - Lisburne
Mk - Kayak(?)-Kekiktuk
sc - schist
ma - mafic rocks
qm - quartz-monzonite
rg - Romanzof granite
nk - Neruokpuk

thrust fault
flow layers(?)
bedding






143°30'
HULAHULA
RIVER
U D
0
1000
2000
3000
4000
3000+
4000
4000
4000
1500
2000
2000
3000
3500
3000
3000 U D
U D
?



EXPLANATION

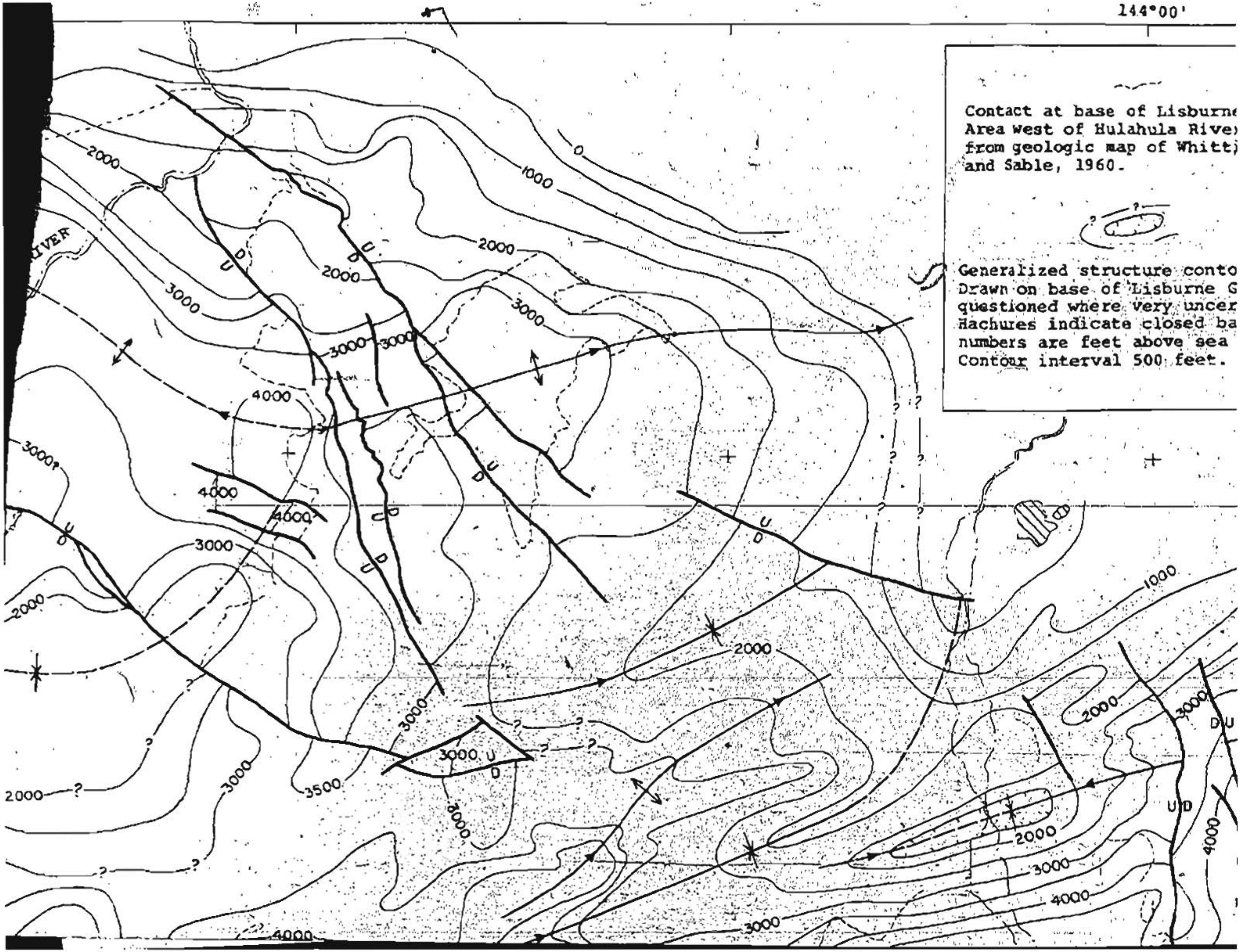
Contact at base of Lisburne Group. Area west of Hulahula River adapted from geologic map of Whittington and Sable, 1960.

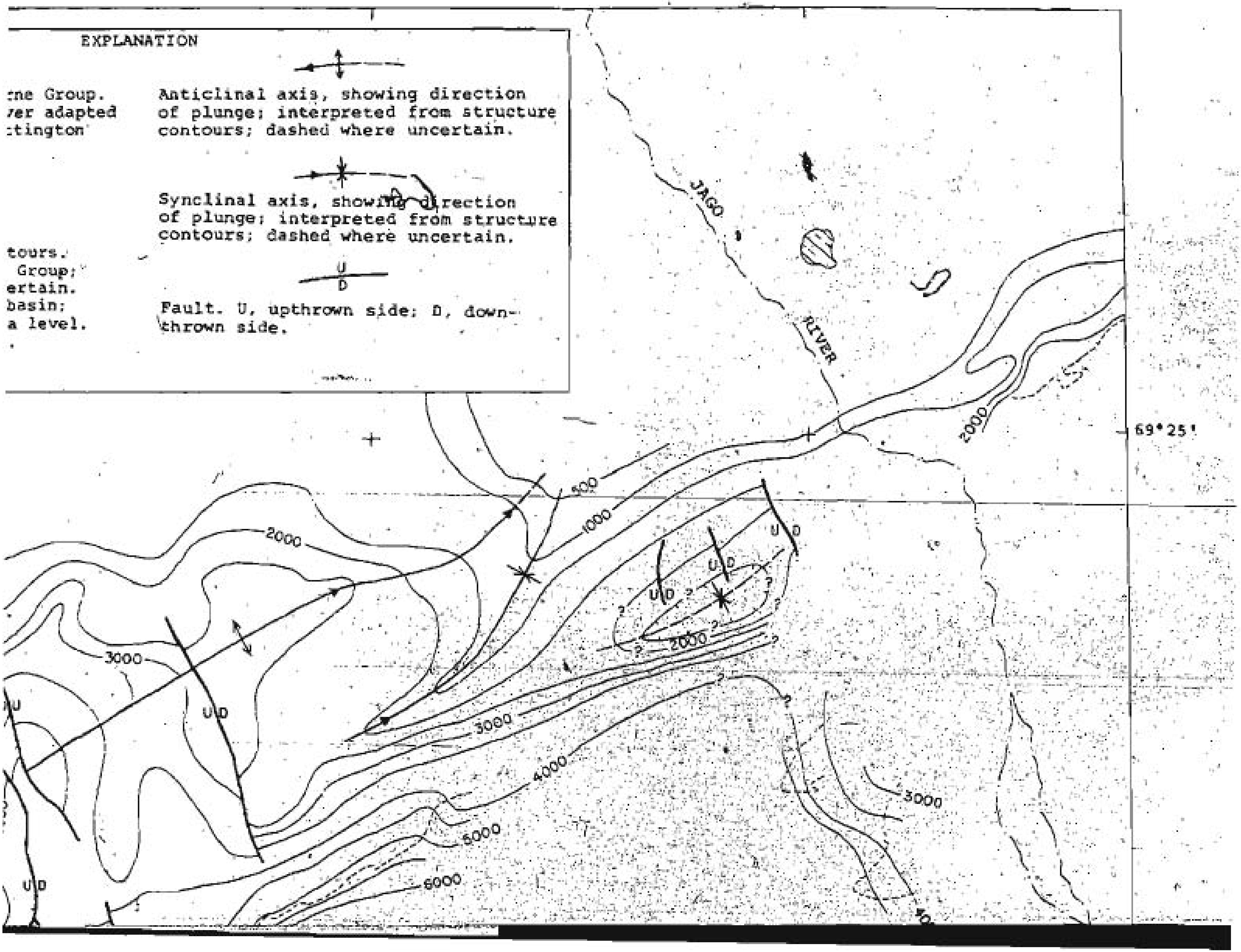
Generalized structure contours. Drawn on base of Lisburne Group; questioned where very uncertain. Hachures indicate closed basin; numbers are feet above sea level. Contour interval 500 feet.

Anticlinal axis, showing direction of plunge; interpreted from structure contours; dashed where uncertain.

Synclinal axis, showing direction of plunge; interpreted from structure contours; dashed where uncertain.

Fault. U, upthrown side; D, downthrown side.


144°00'
Contact at base of Lisburne
Area west of Hulahula Rive
from geologic map of Whitt
and Sable, 1960.
Generalized structure conto
Drawn on base of Lisburne G
questioned where very uncer
Hachures indicate closed ba
numbers are feet above sea
Contour interval 500 feet.
RIVER
0
1000
2000
3000
3500
4000
U
D
?



EXPLANATION

rne Group.
ver adapted
ctington

tours.
Group;
ertain.
basin;
a level.

Anticlinal axis, showing direction of plunge; interpreted from structure contours; dashed where uncertain.

Synclinal axis, showing direction of plunge; interpreted from structure contours; dashed where uncertain.

Fault. U, upthrown side; D, downthrown side.

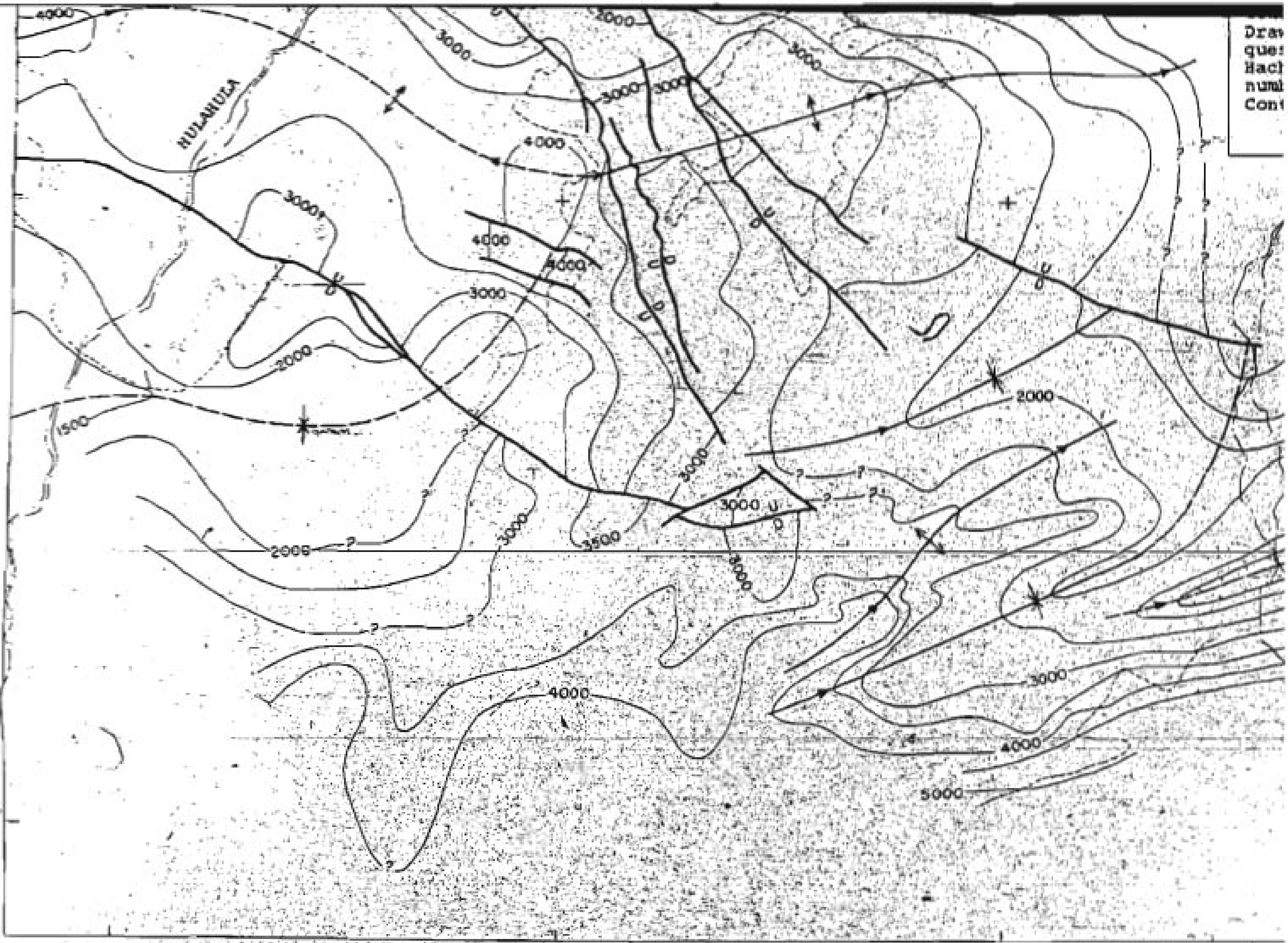
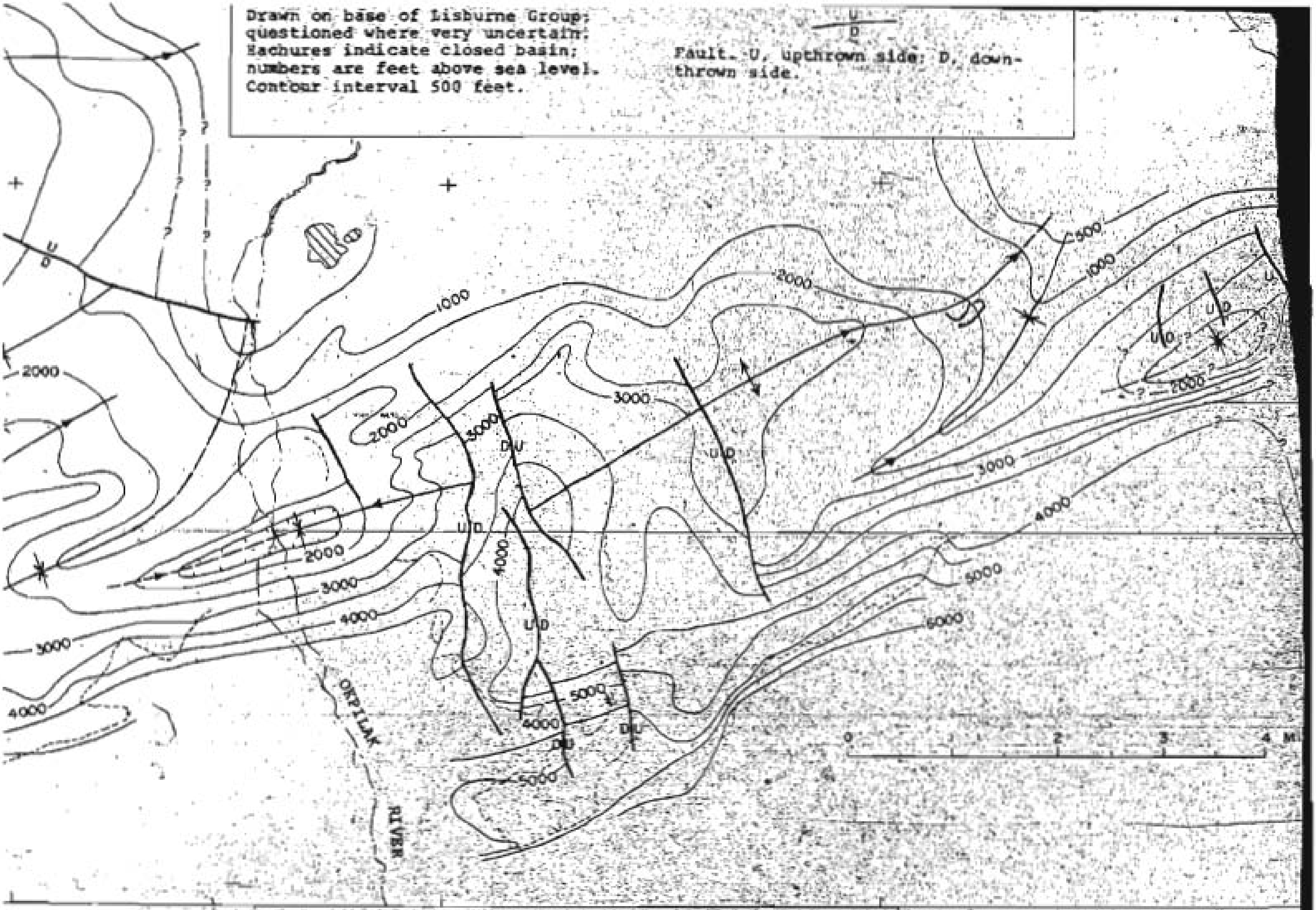


PLATE 3. GENERALIZED STRUCTUR
GROUP, NORTH SIDE OF



TE 3. GENERALIZED STRUCTURE MAP SHOWING BASE OF LISBURNE GROUP, NORTH SIDE OF ROMANZOF MOUNTAINS, ALASKA.

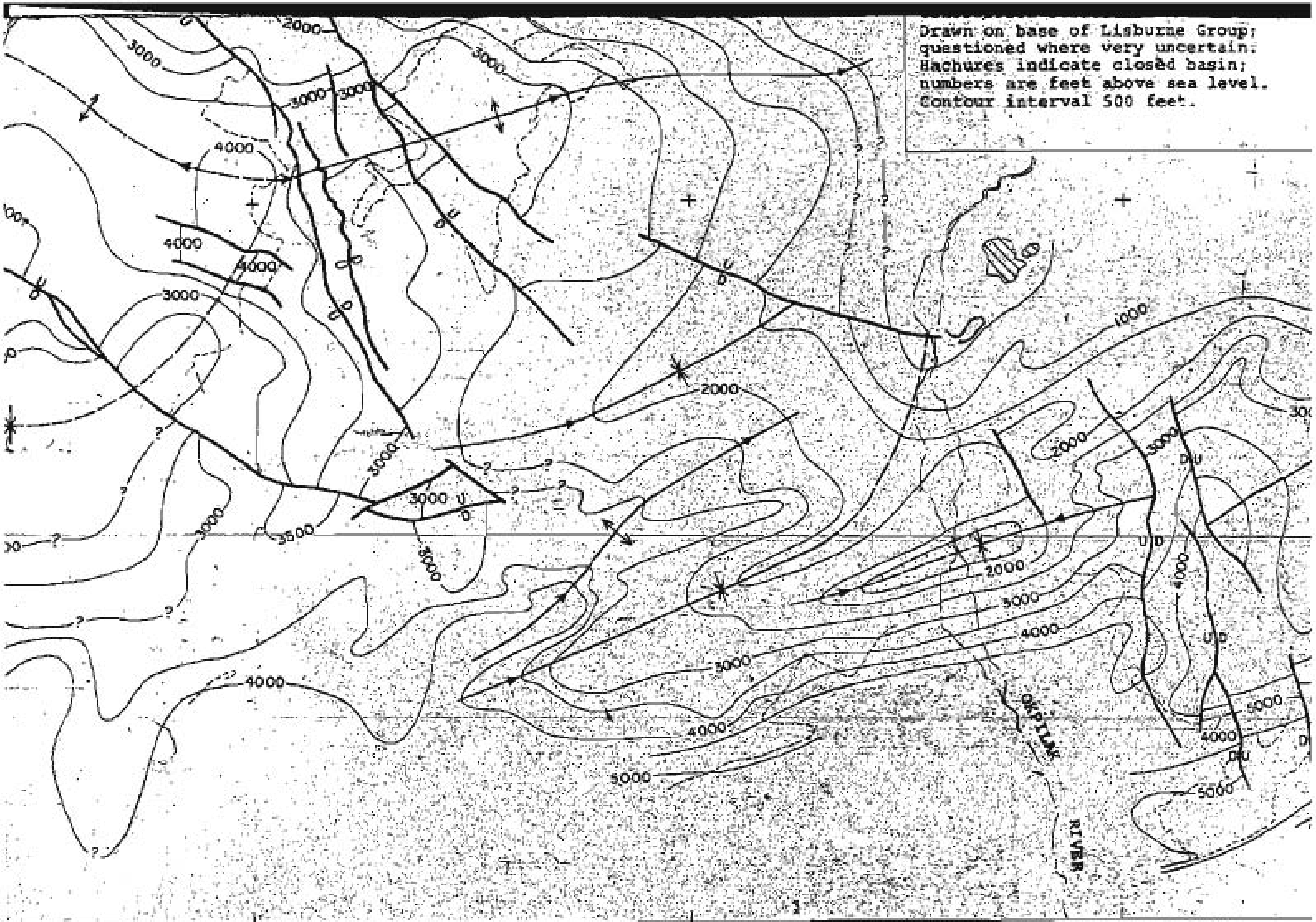
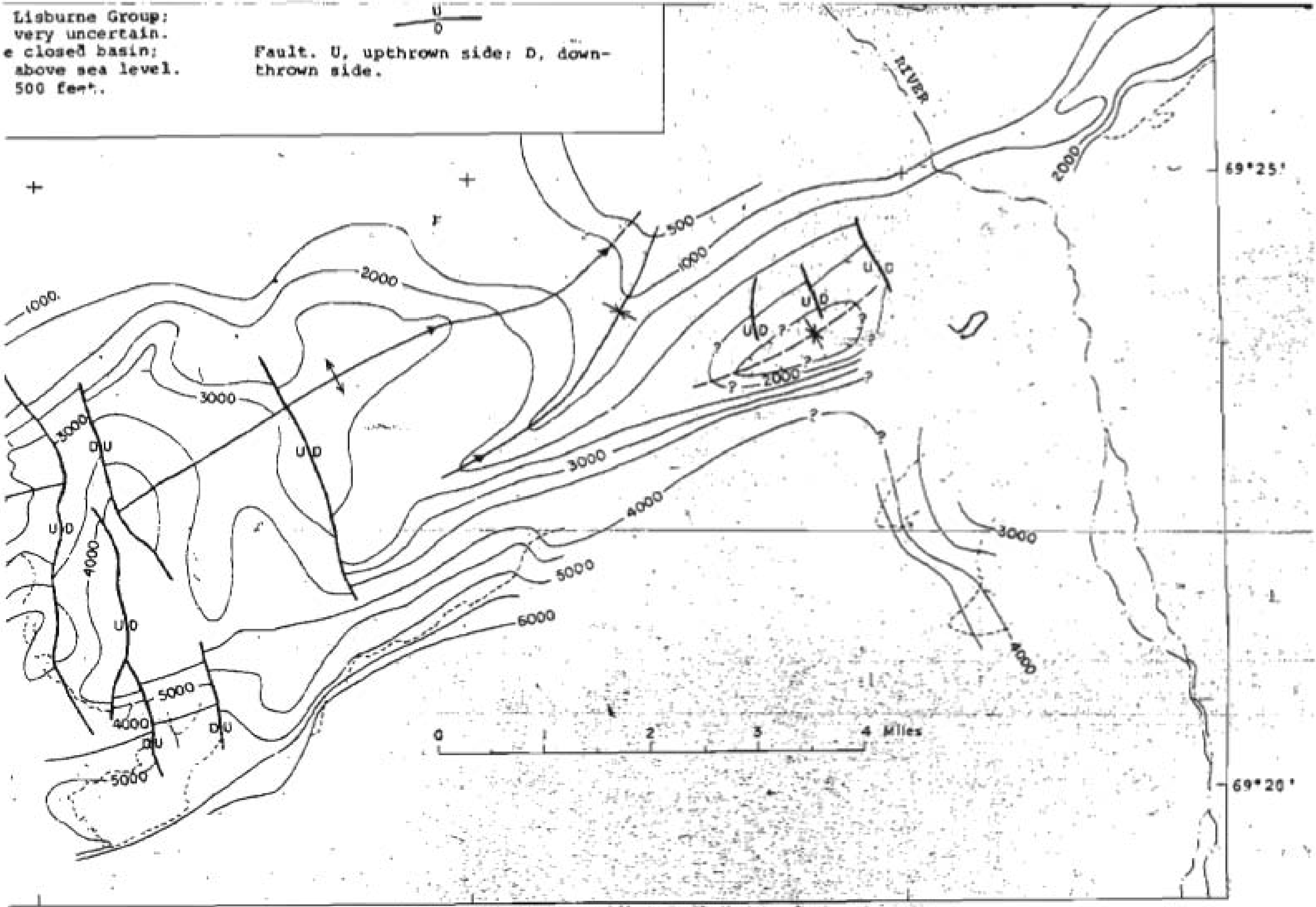
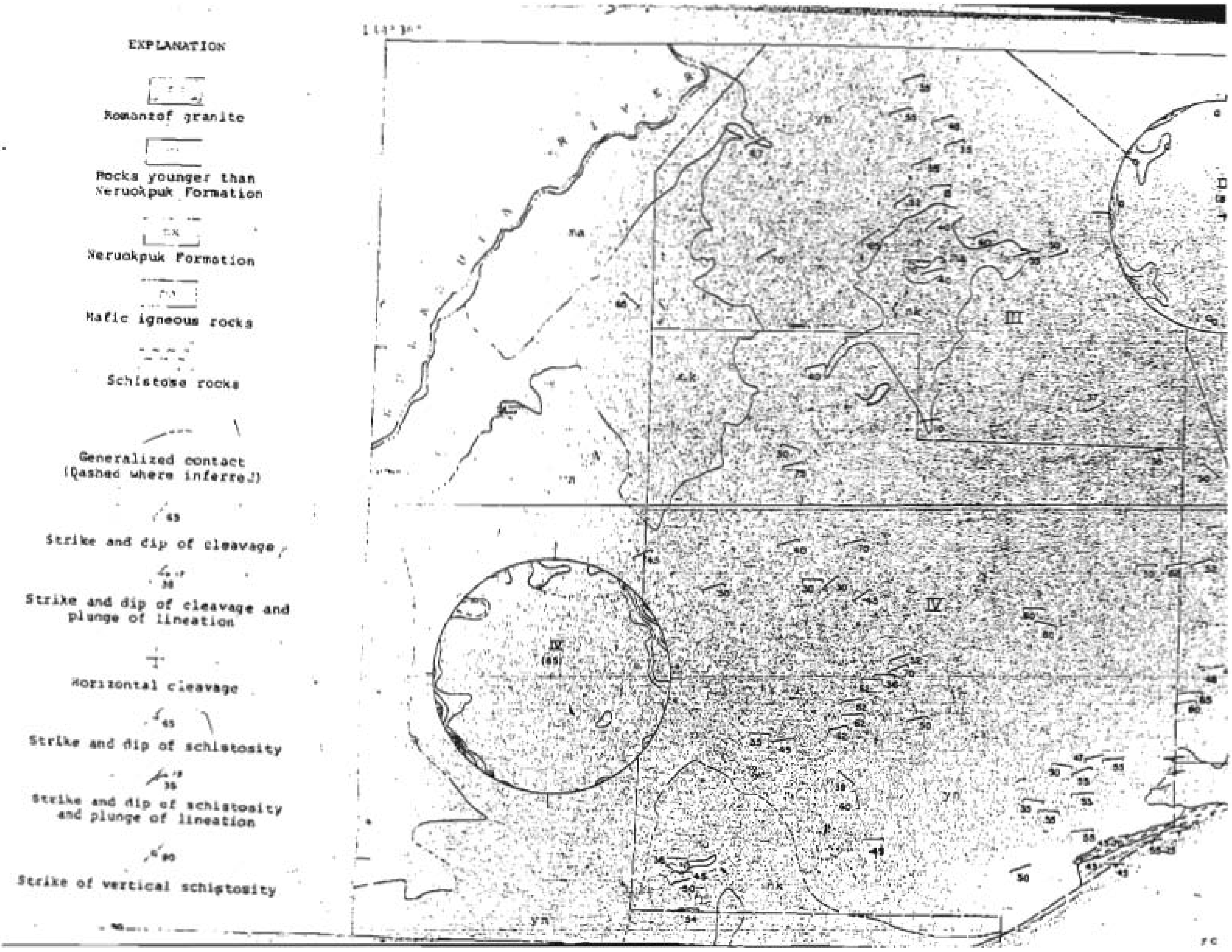


PLATE 3. GENERALIZED STRUCTURE MAP SHOWING BASE OF LISBURNE GROUP, NORTH SIDE OF ROMANZOF MOUNTAINS, ALASKA.

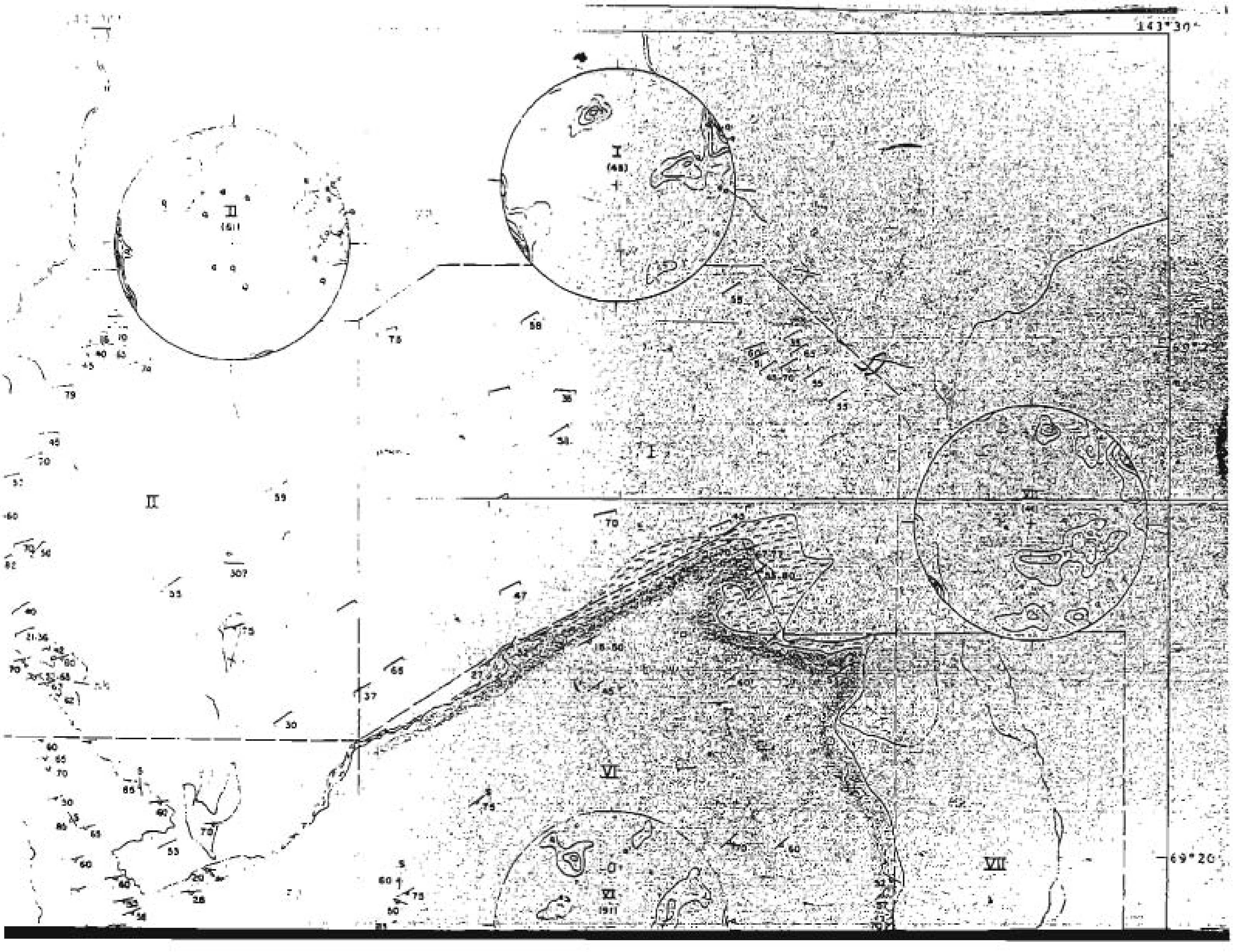


NG BASE OF LISBURNE
OUNTAINS, ALASKA.


EXPLANATION
Romanzof granite
Rocks younger than Neruokpuk Formation
Neruokpuk Formation
Mafic igneous rocks
Schistose rocks
Generalized contact (Dashed where inferred)
Strike and dip of cleavage
Strike and dip of cleavage and plunge of lineation
Horizontal cleavage
Strike and dip of schistosity
Strike and dip of schistosity and plunge of lineation
Strike of vertical schistosity
III
IV
IV (65)
yn
nk
na


144°00'
I
II
III
(84)
IV
V
VI
(91)

144°00'
III
(64)
II
(61)
IV
(83)
III
IV
V
yn
nk
nk²
ma
s


143°30'
69°20'
I
(48)
II
(61)
III
(46)
VI
(91)
I
II
VI
VII

and plunge of lineation

50

Strike of vertical schistosity

90 50

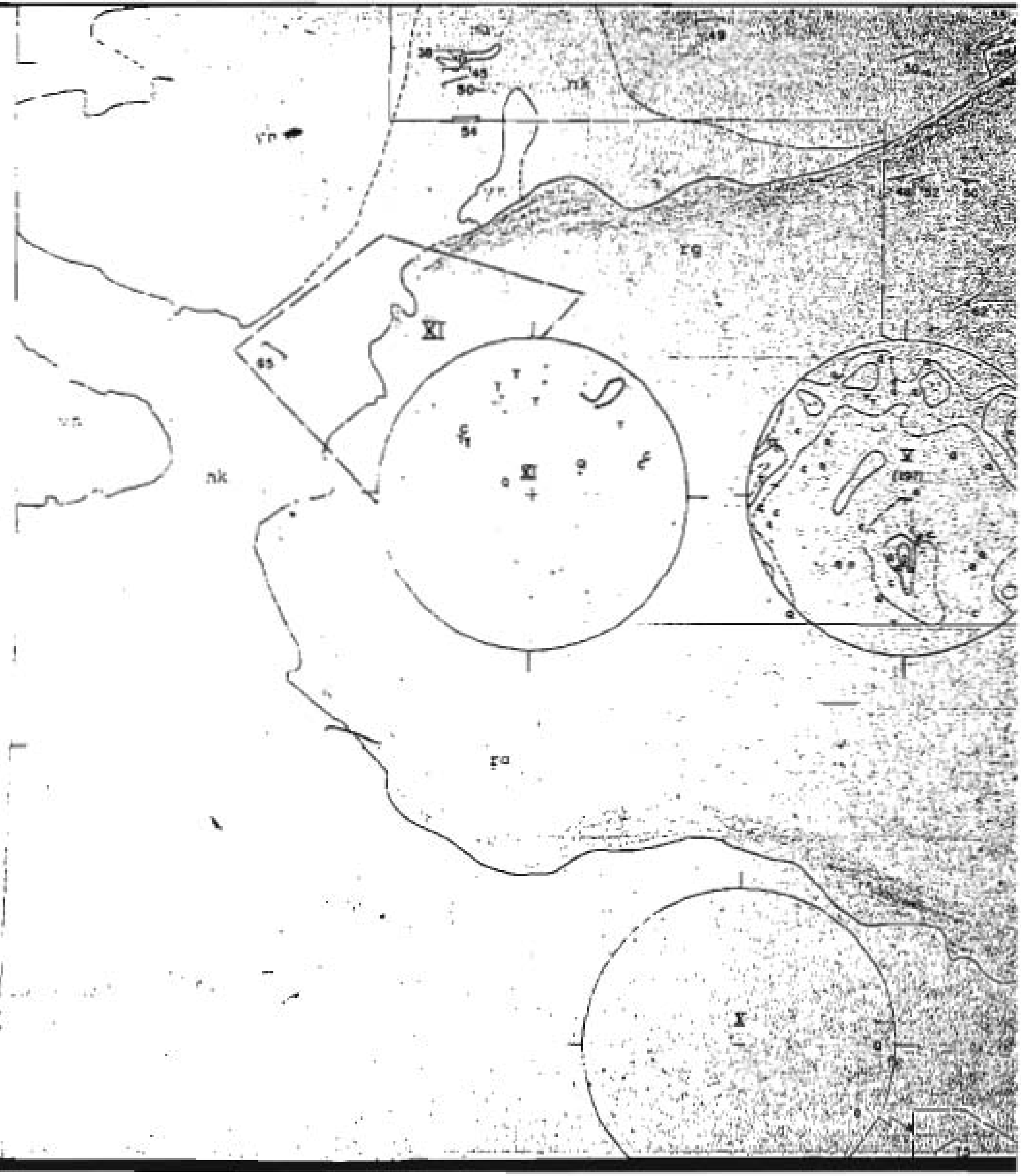
Strike and dip of gneissic or gneissoid granite foliation

90 s s 65

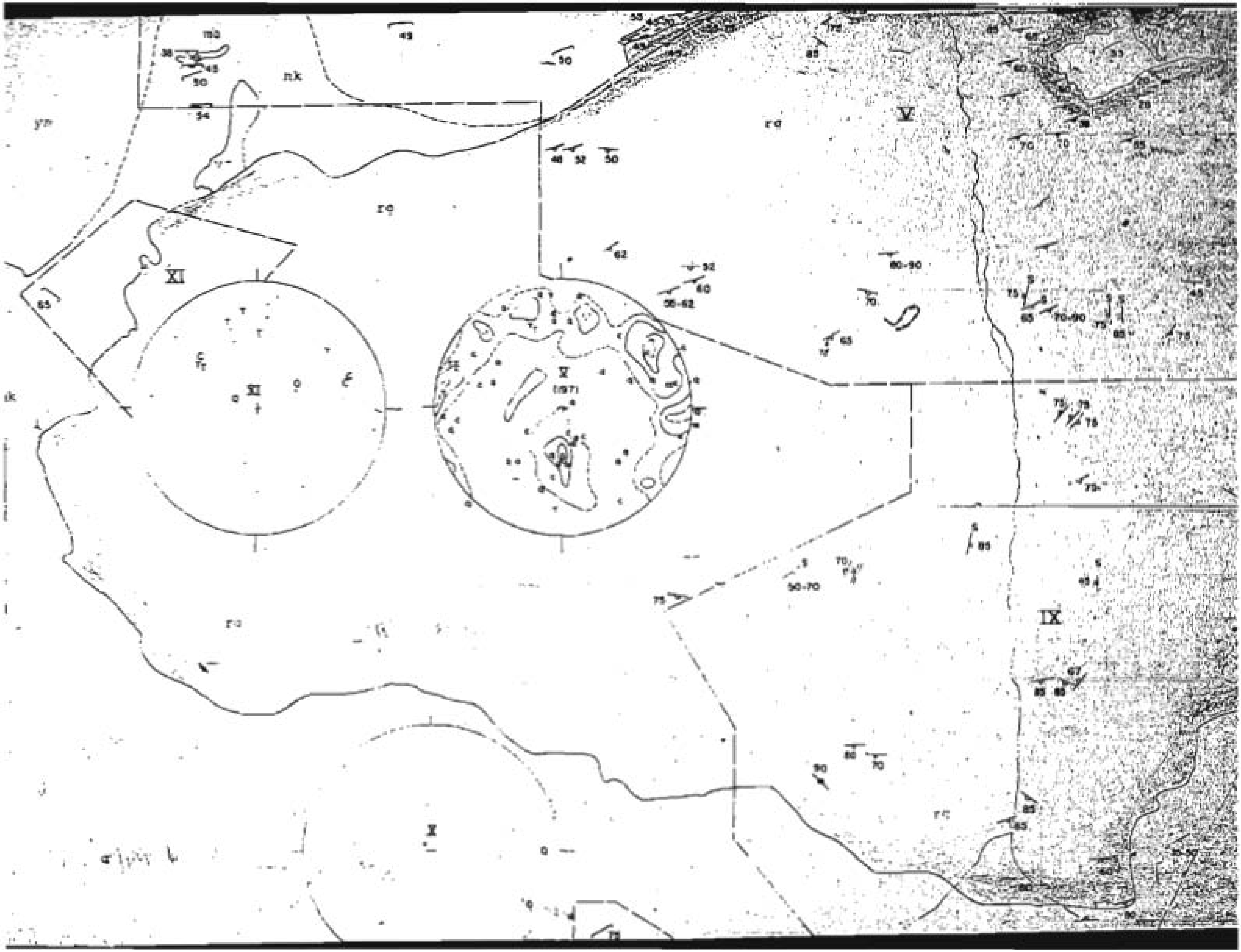
Strike and dip of schistose zone (Schistosity in zone nearly parallel to trend)

I

Subarea for which joint readings are shown in included or adjoining lower hemisphere equal-area projection. In projections, number of poles in parentheses; solid contours indicate 2,4,6,8, 10, and 12 percent per 1 percent of area; dashed contours indicate odd-number percentages in areas of pole maxima and 1 percent value in subareas V and IX. Contours for single isolated joint poles of 2 percent value not plotted. Dots indicate poles of joints in small isolated subareas. Q, T, and C indicate poles of quartz, tourmaline, and chlorite veins; not used in contour delineation.



V
IX
V
(197)
IX
(192)
VI
(91)
80-90
50-70
70-90
35-62
35-50
70-80
0
1
2
3


mb
nk
yn
ro
V
XI
IX
X
(197)
50-70
80-90
56-62
70-90


VI
(91)
IX
(192)
VII
VIII
(48)
VIII
X
0
1
2
3
4 Miles
50-70
70-90
30-70
70
60
53
85
65

ing lower hemisphere equal-area projection. In projections, number of poles in parentheses; solid contours indicate 2,4,6,8, 10, and 12 percent per 1 percent of area; dashed contours indicate odd-number percentages in areas of pole maxima and 1 percent value in subareas V and IX. Contours for single isolated joint poles of 2 percent value not plotted. Dots indicate poles of joints in small isolated subareas. Q, T, and C indicate poles of quartz, tourmaline, and chlorite veins; not used in contour delineation.

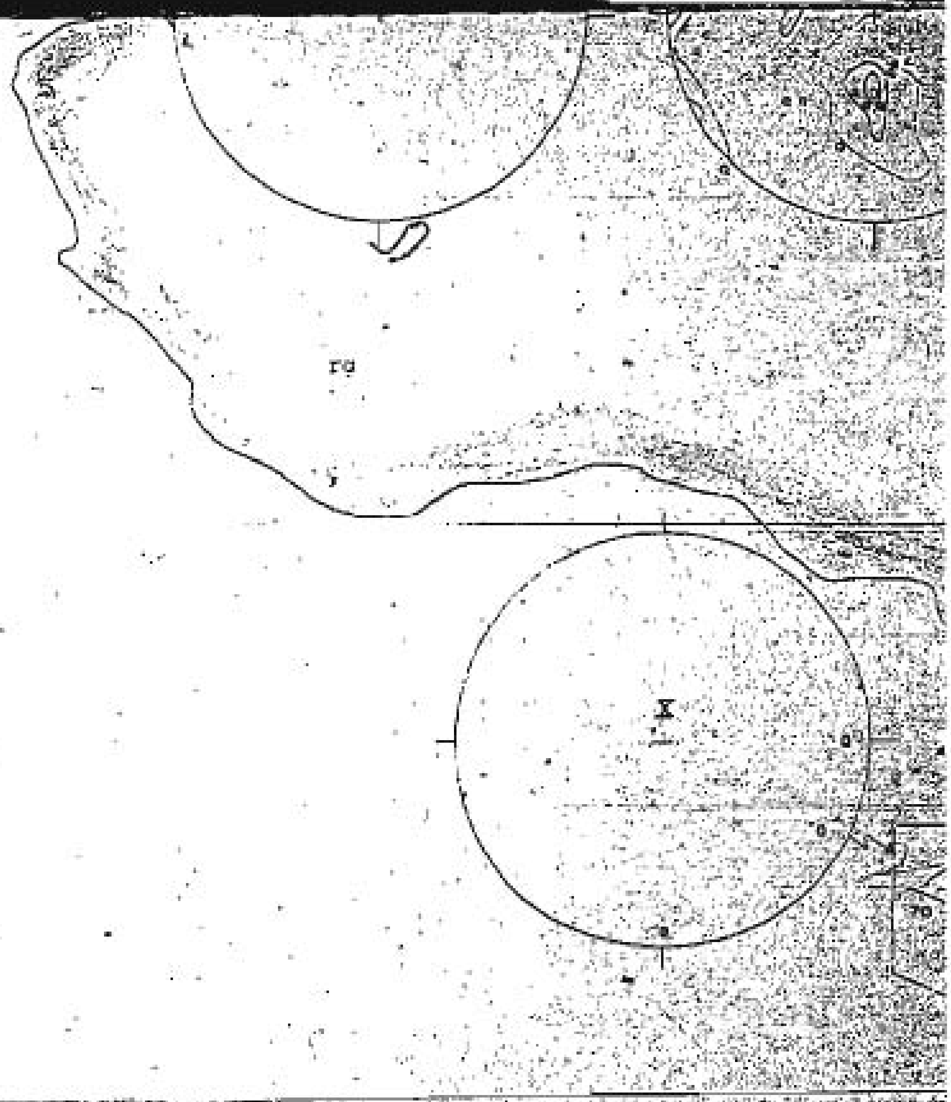


PLATE 4 — MA
JO

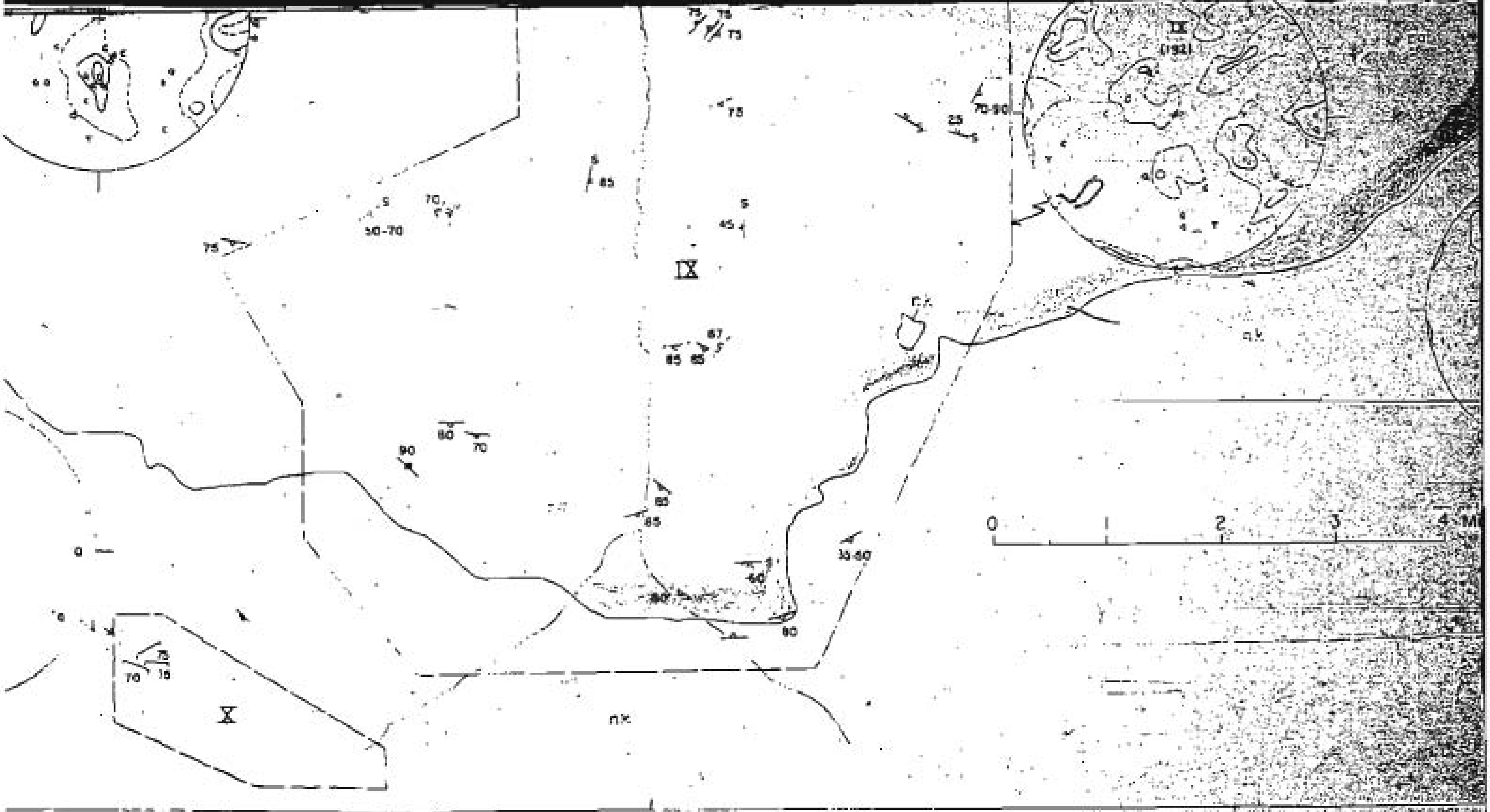


PLATE 4. MAP SHOWING ATTITUDES OF SECONDARY FOLIATION, SCHISTOSE ZONES, JOINTS, AND VEINS IN ROMANZOF MOUNTAINS, ALASKA.

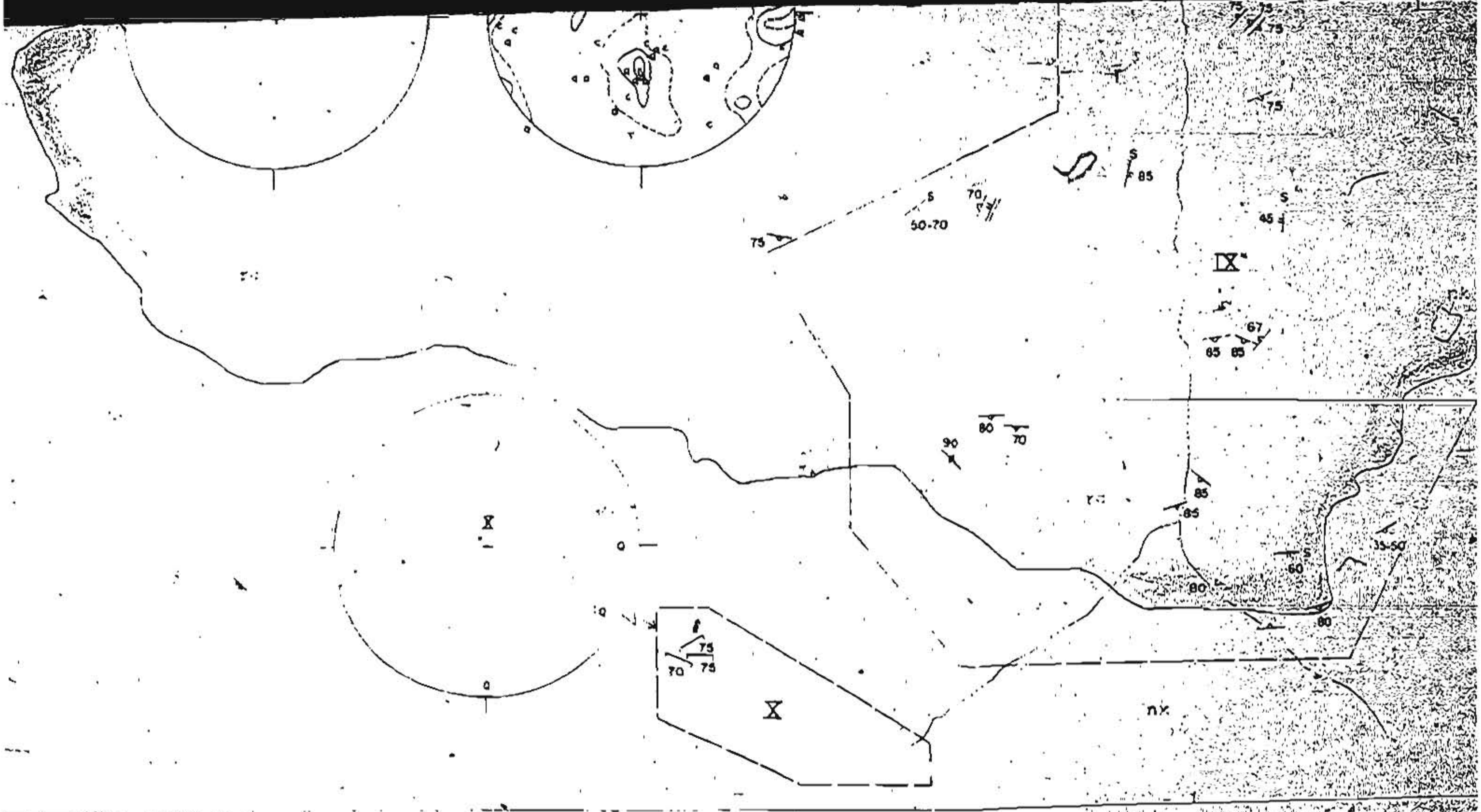
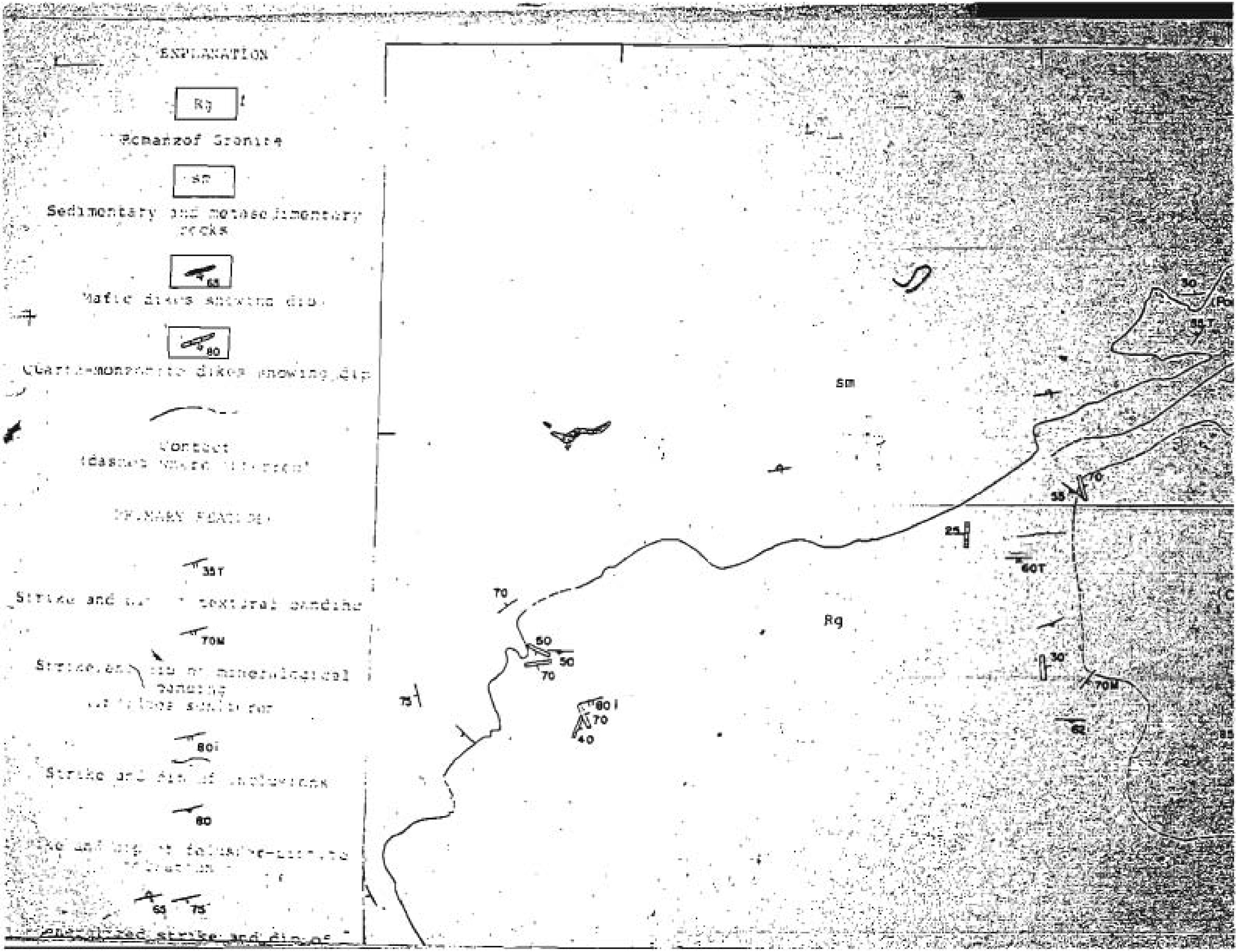
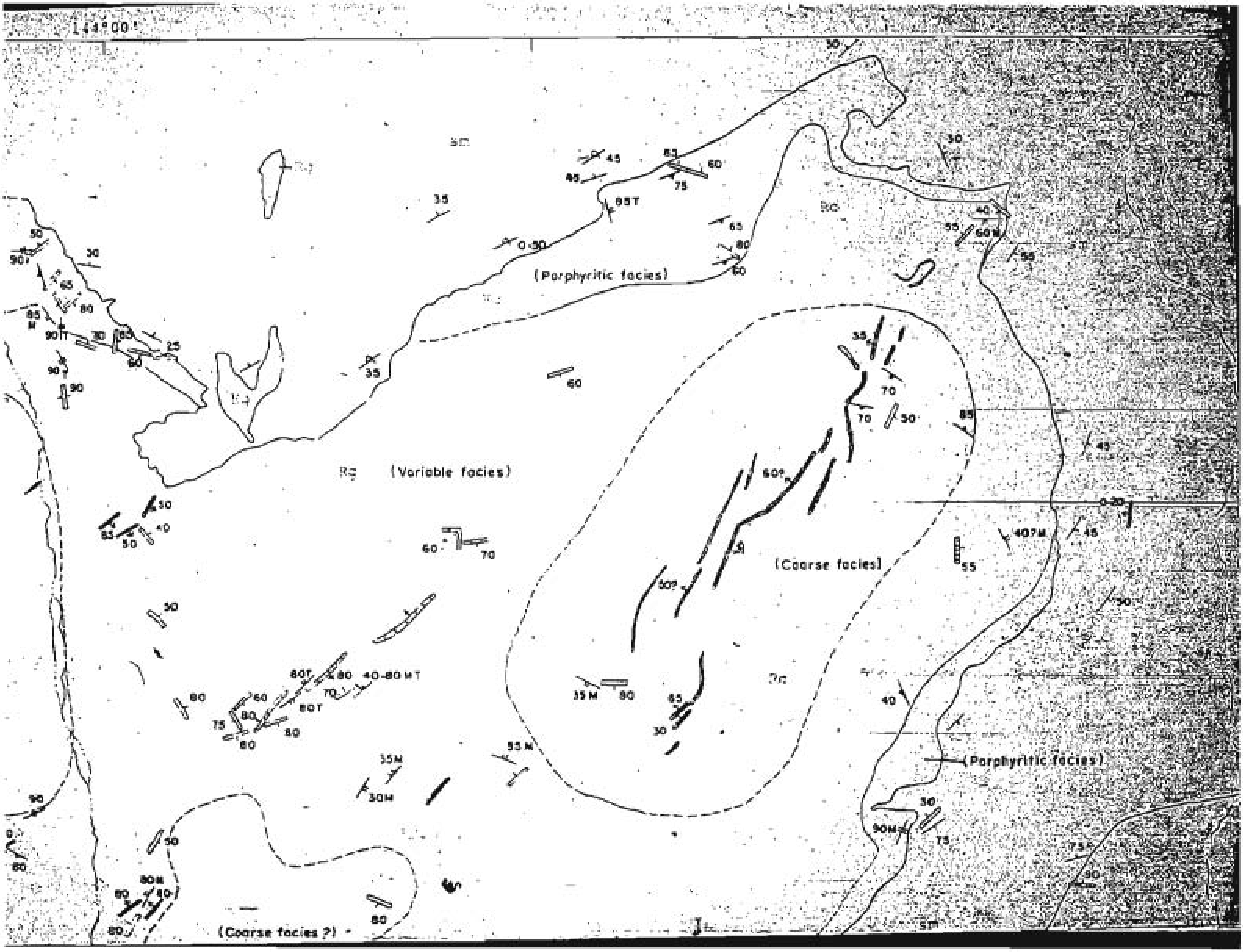


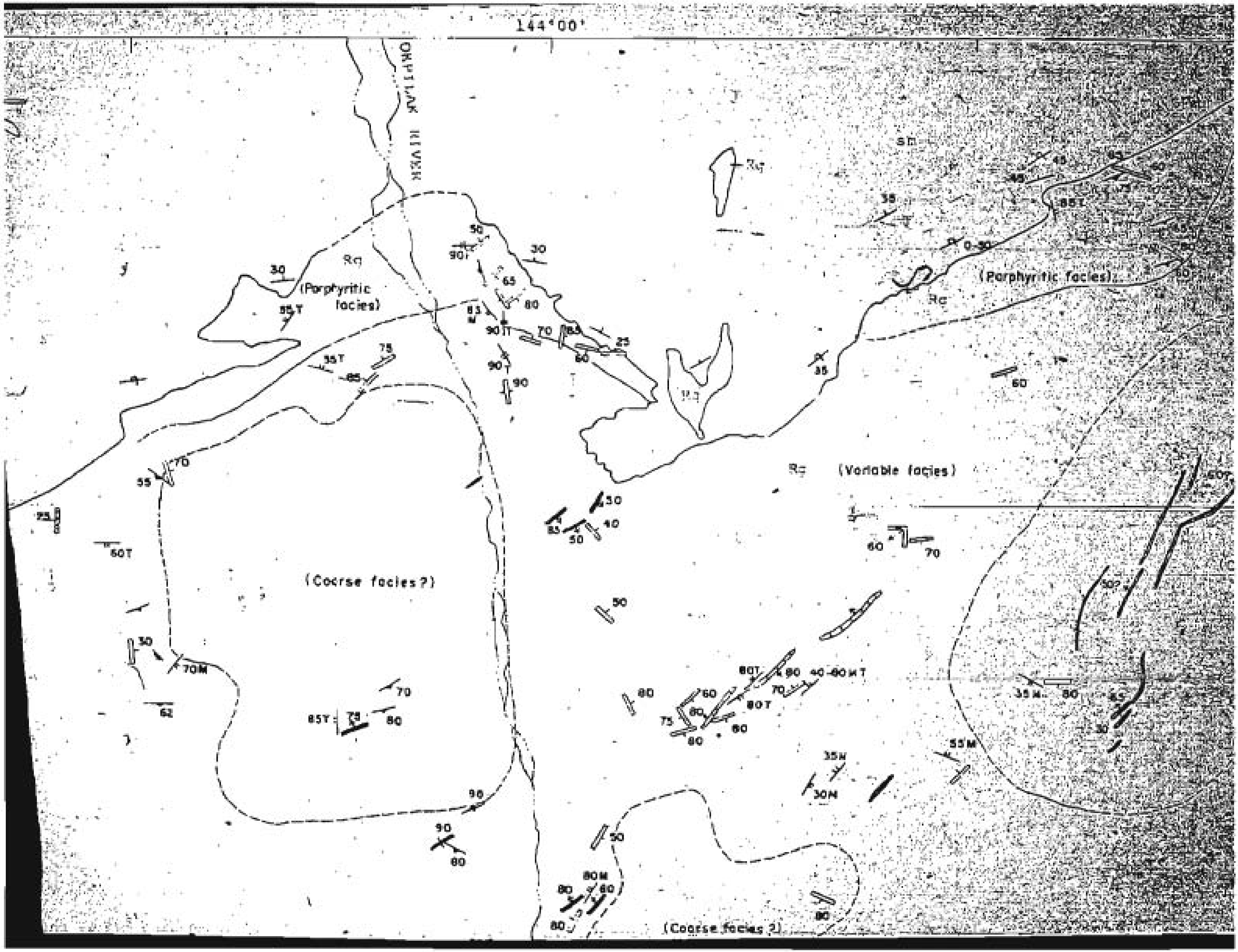
PLATE 4. MAP SHOWING ATTITUDES OF SECONDARY FOLIATION, SCHISTOSE ZONES, JOINTS, AND VEINS IN ROMANZOF MOUNTAINS, ALASKA.

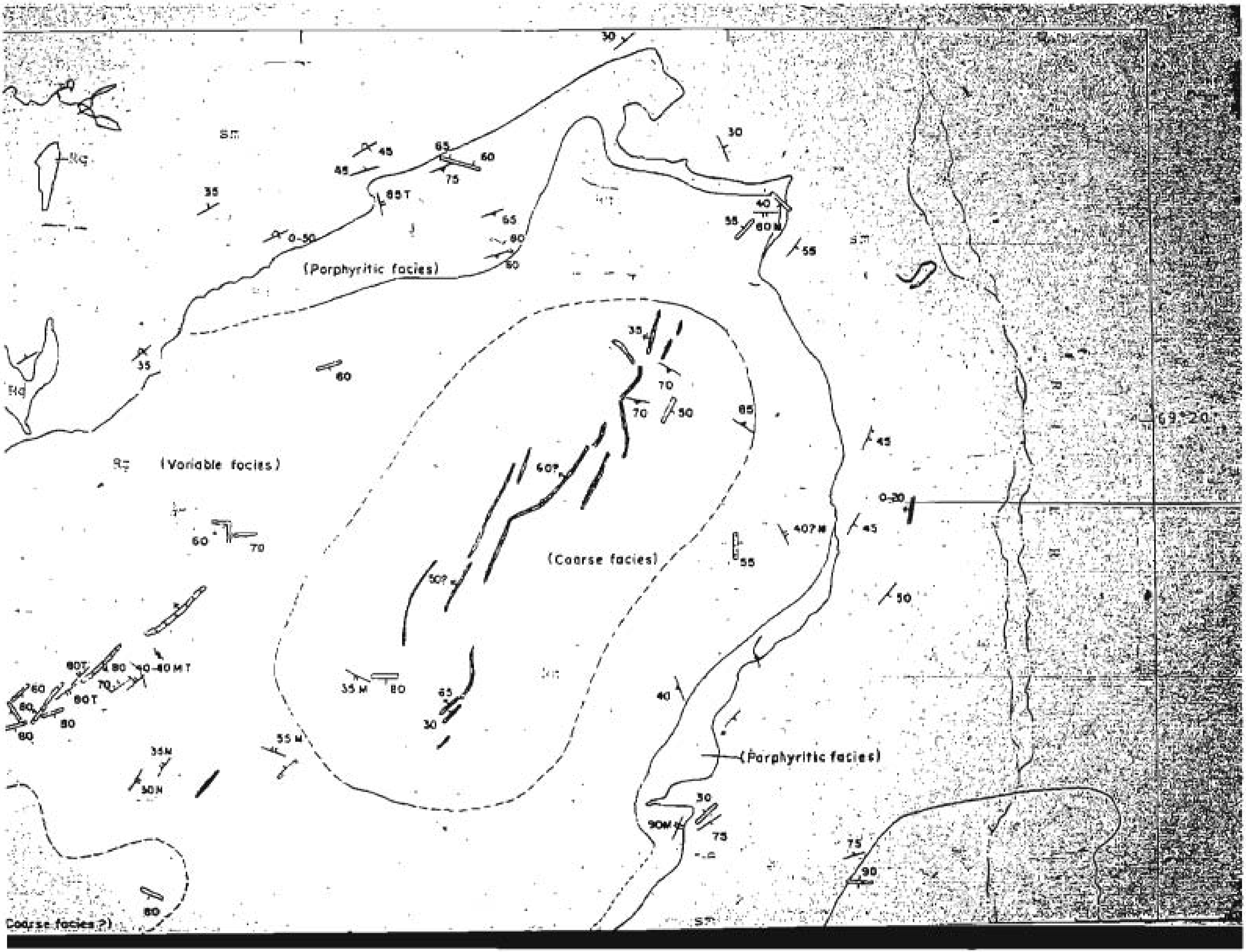

IX
(192)
75
75
70-90
25
5
5
VIII
VIII
cc
60
80
rg
nk
69°35'
0
1
2
3
4 Miles
30-50
60
80

TOSE ZONES.


EXPLANATION
Rg
Romanzof Granite
sm
Sedimentary and metasedimentary rocks
65
Mafic dikes showing dip
80
Quartz-monzonite dikes showing dip
Contact
(dashed where inferred)
PRIMARY FEATURES
35T
Strike and dip of textural banding
70M
Strike and dip of mineralogical banding or schlieren
80i
Strike and dip of inclusions
80
Strike and dip of foliation-cutting fractures
65
75
Generalized strike and dip of
sm
Rg
30
35T
70
55
25
60T
70
50
50
70
75
80
70
40
30
70M
62


144°00'
(Porphyritic facies)
(Variable facies)
(Coarse facies)
(Coarse facies ?)
(Porphyritic facies)
Rg
Sm


144°00'
OKPILAK RIVER
(Porphyritic facies)
(Coarse facies?)
(Variable facies)
(Porphyritic facies)
(Coarse facies ?)
85T
55T
70M
60T
0-30
40-60MT
35M
30M
55M
50?



(Porphyritic facies)
(Variable facies)
(Coarse facies)
(Porphyritic facies)
Coarse facies ?)
69°20'
35
45
45
65
60
75
85T
0-50
65
80
60
30
30
40
55
60 M
55
35
60
35
70
70
50
85
60?
45
0-20
407 M
45
55
50?
50
60
70
80T
80
40-80 MT
70
60
80T
80
80
80
35 M
80
65
30
55 M
35N
30N
40
30
90M
75
75
90
80

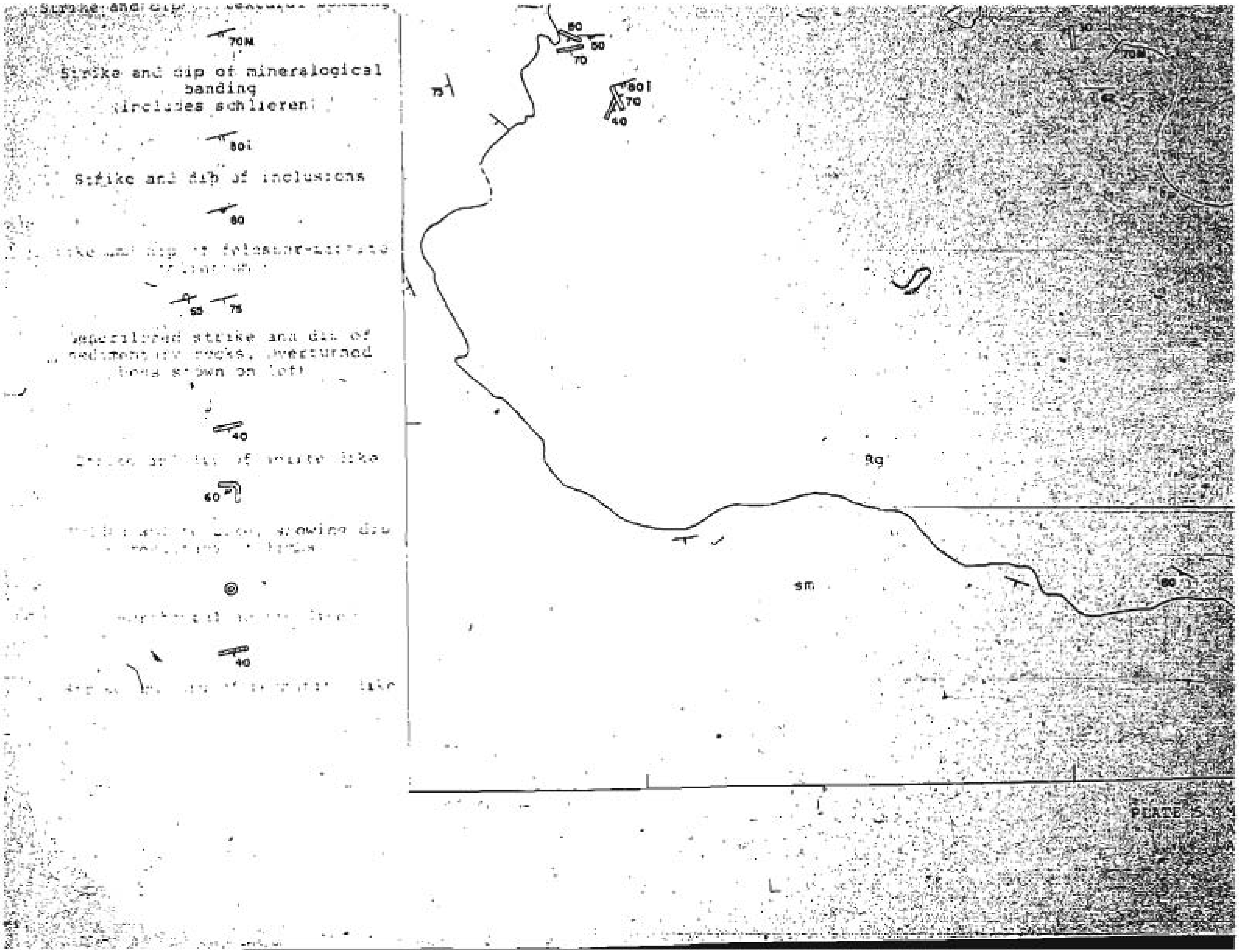

Strike and dip
70M
Strike and dip of mineralogical banding (includes schlieren)
80i
Strike and dip of inclusions
80
55
75
Generalized strike and dip of sedimentary rocks, overturned beds shown on left
40
60
40
50
50
70
75
80I
70
40
Rg
sm
80
70M

PLATE 5

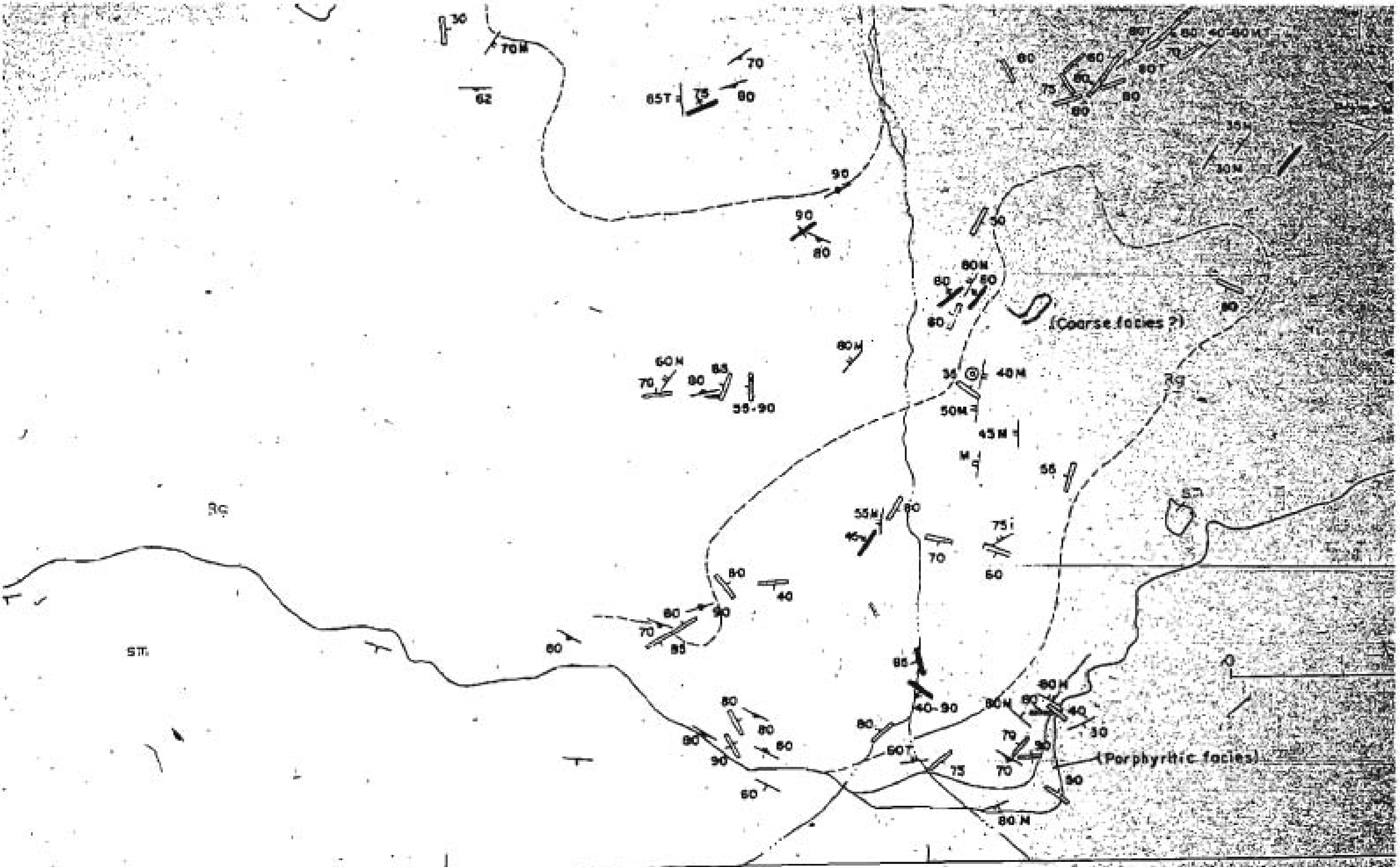


PLATE 5. MAP SHOWING ATTITUDES AND TRENDS OF PRIMARY FEATURES, APLITE, PEGMATITE, AND DARK DIKES IN ROMANZOF GRANITE AND INTRUDED ROCK, ROMANZOF MOUNTAINS, ALASKA.

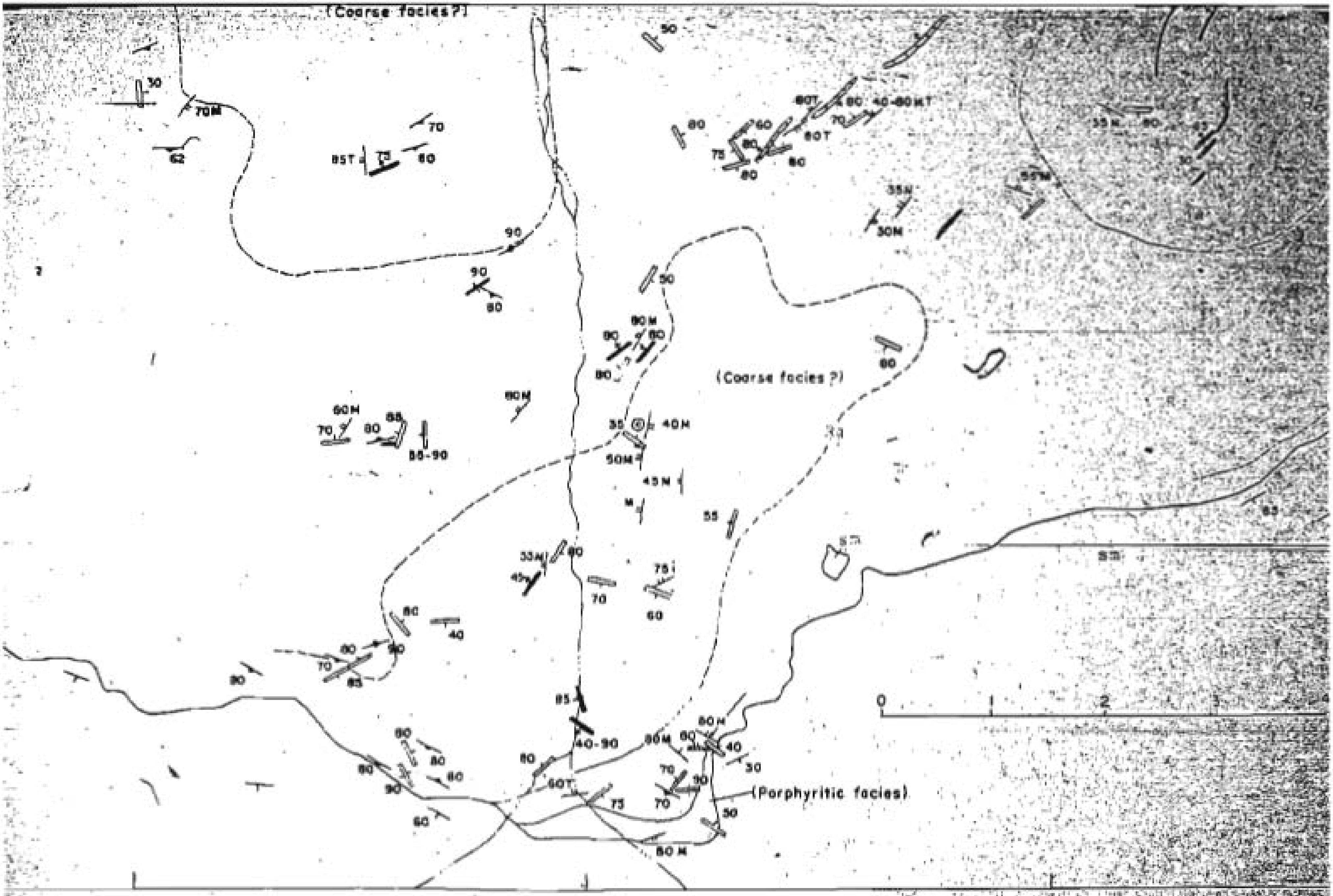
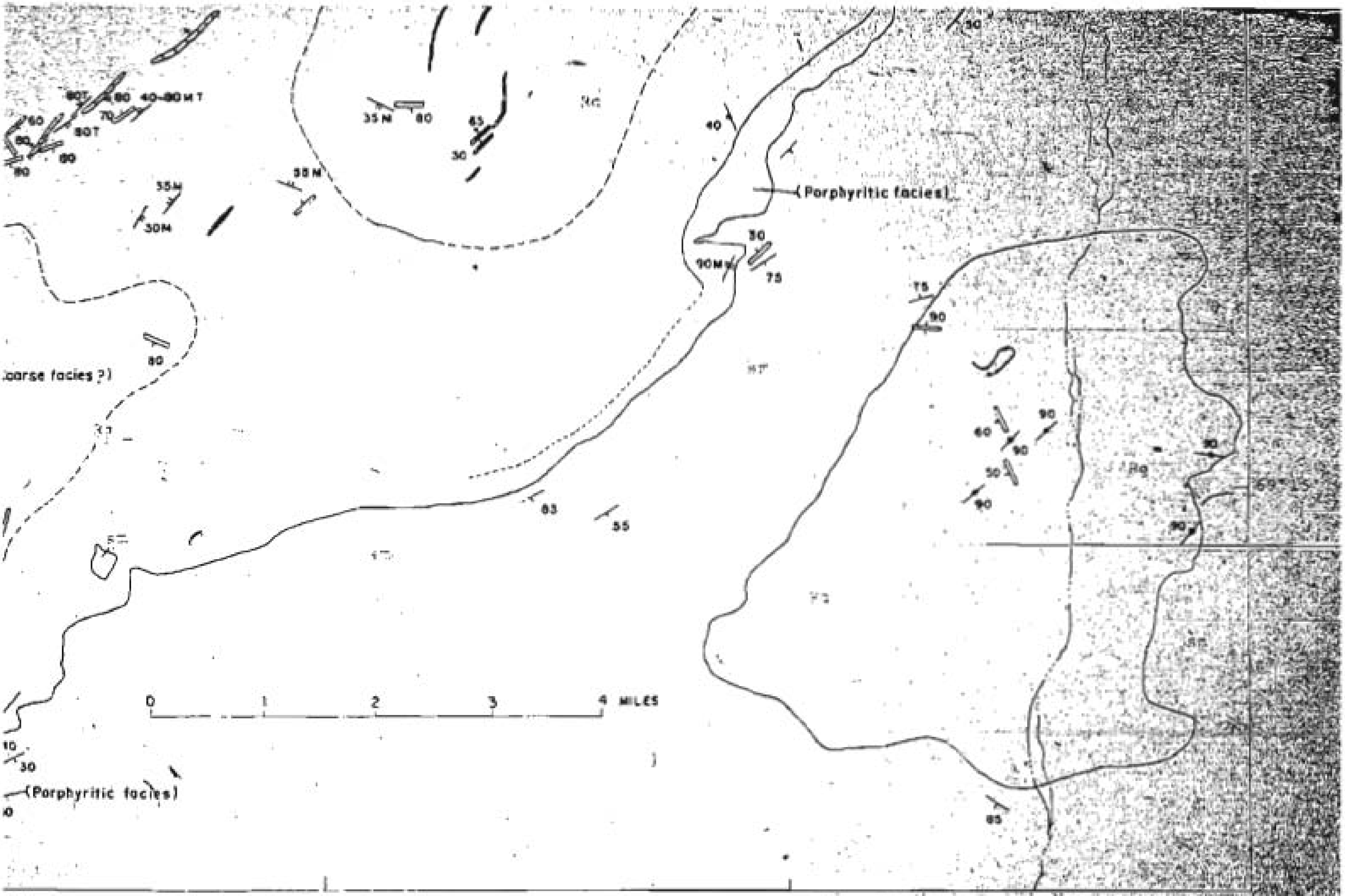
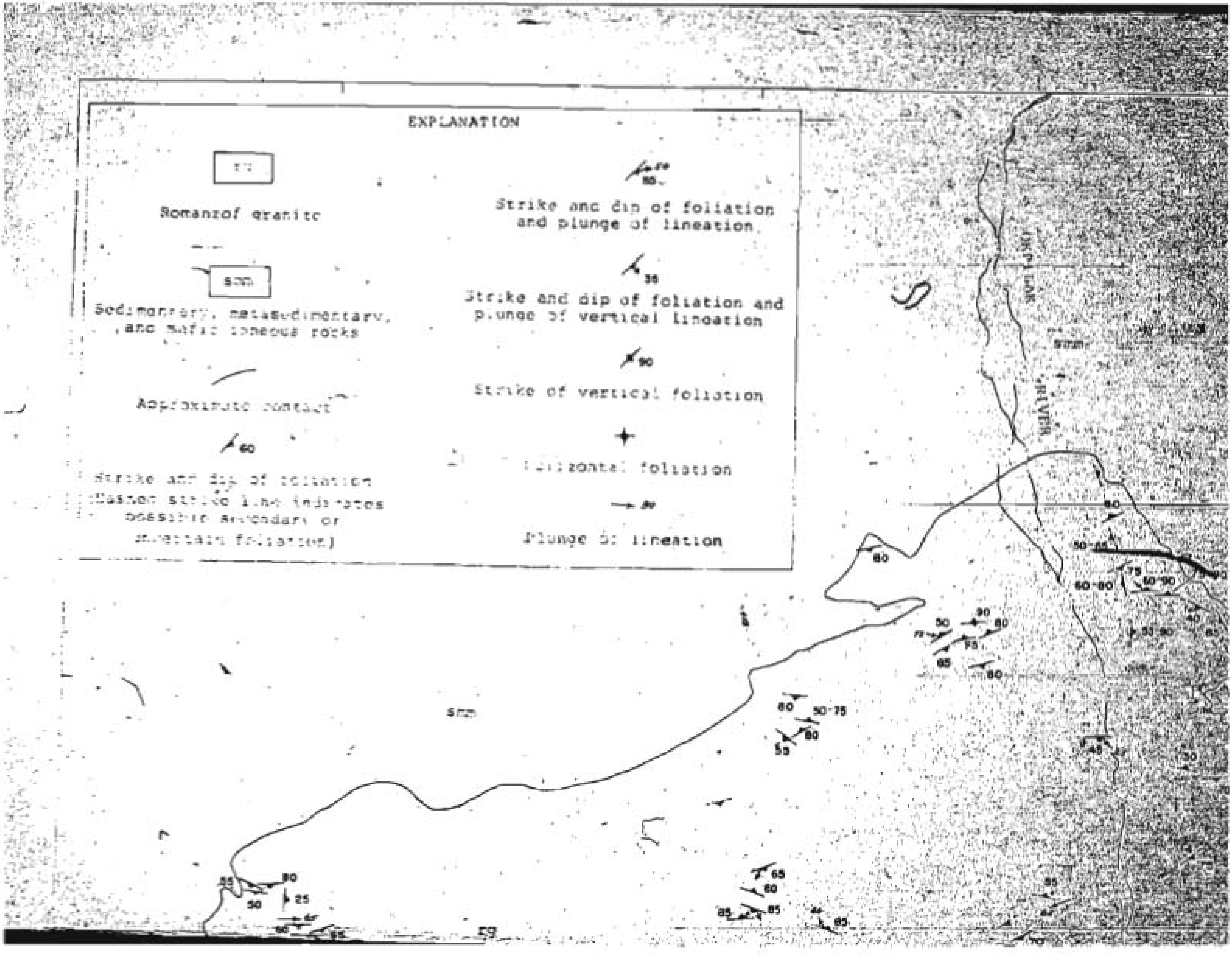


PLATE 5. MAP SHOWING ATTITUDES AND TRENDS OF PRIMARY FEATURES, APLITE, PEGMATITE, AND DARK DIKES IN ROMANZOF GRANITE AND INTRUDED ROCK, ROMANZOF MOUNTAINS, ALASKA.



MARY FEATURES,
MANZOF GRANITE
ALASKA.


EXPLANATION
Romanzof granite
Sm
Sedimentary, metasedimentary, and mafic igneous rocks
Approximate contact
60
Strike and dip of foliation (Dashed strike line indicates possible secondary or uncertain foliation)
80
Strike and dip of foliation and plunge of lineation
35
Strike and dip of foliation and plunge of vertical lineation
90
Strike of vertical foliation
Horizontal foliation
Plunge of lineation
OKPILAK
RIVER
Sm


30
35
45
70
63
67
60
60
72
70
80
70
75
85
85
50
30
30-50
70-90
63
80
70
85
90

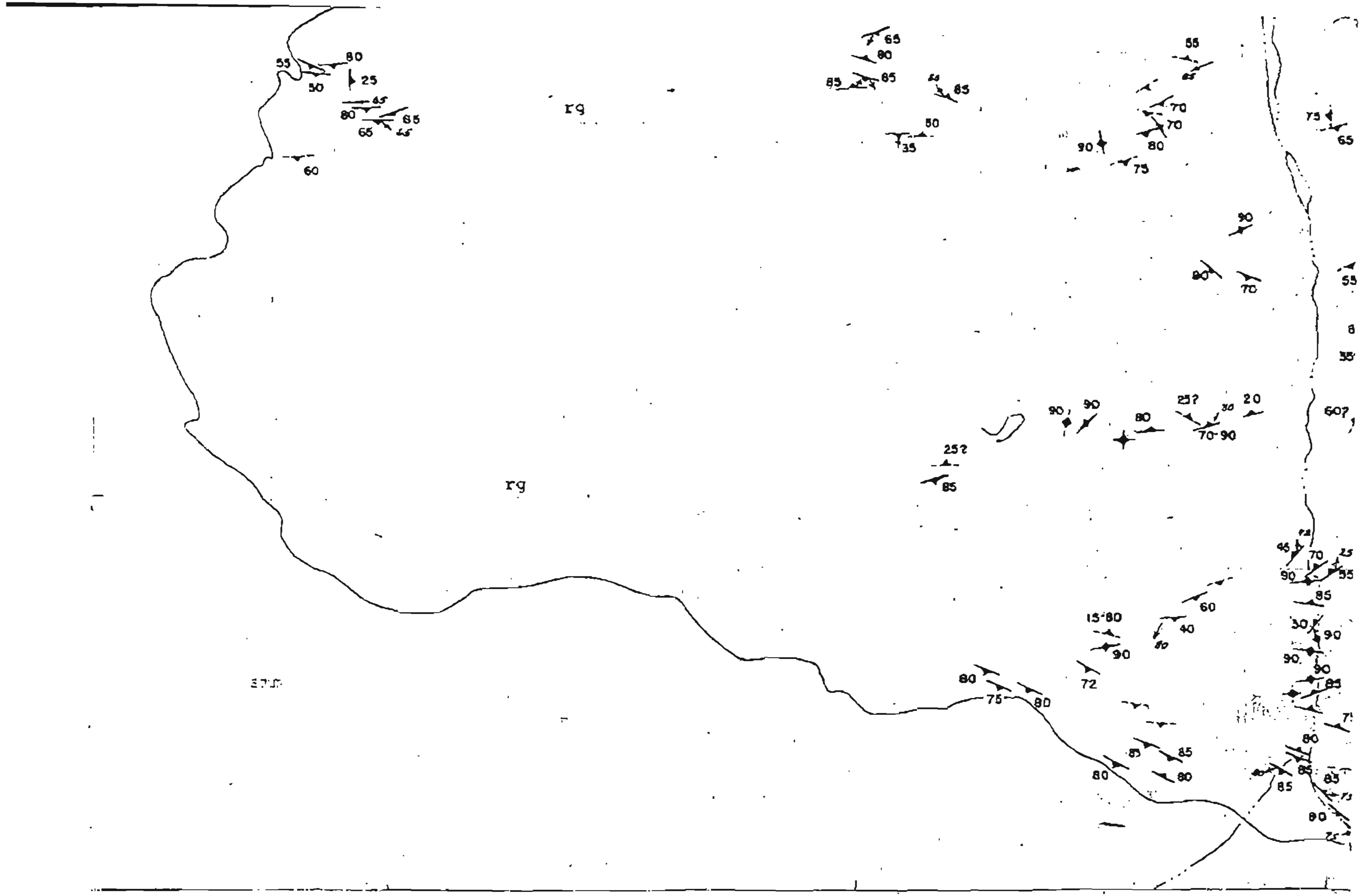
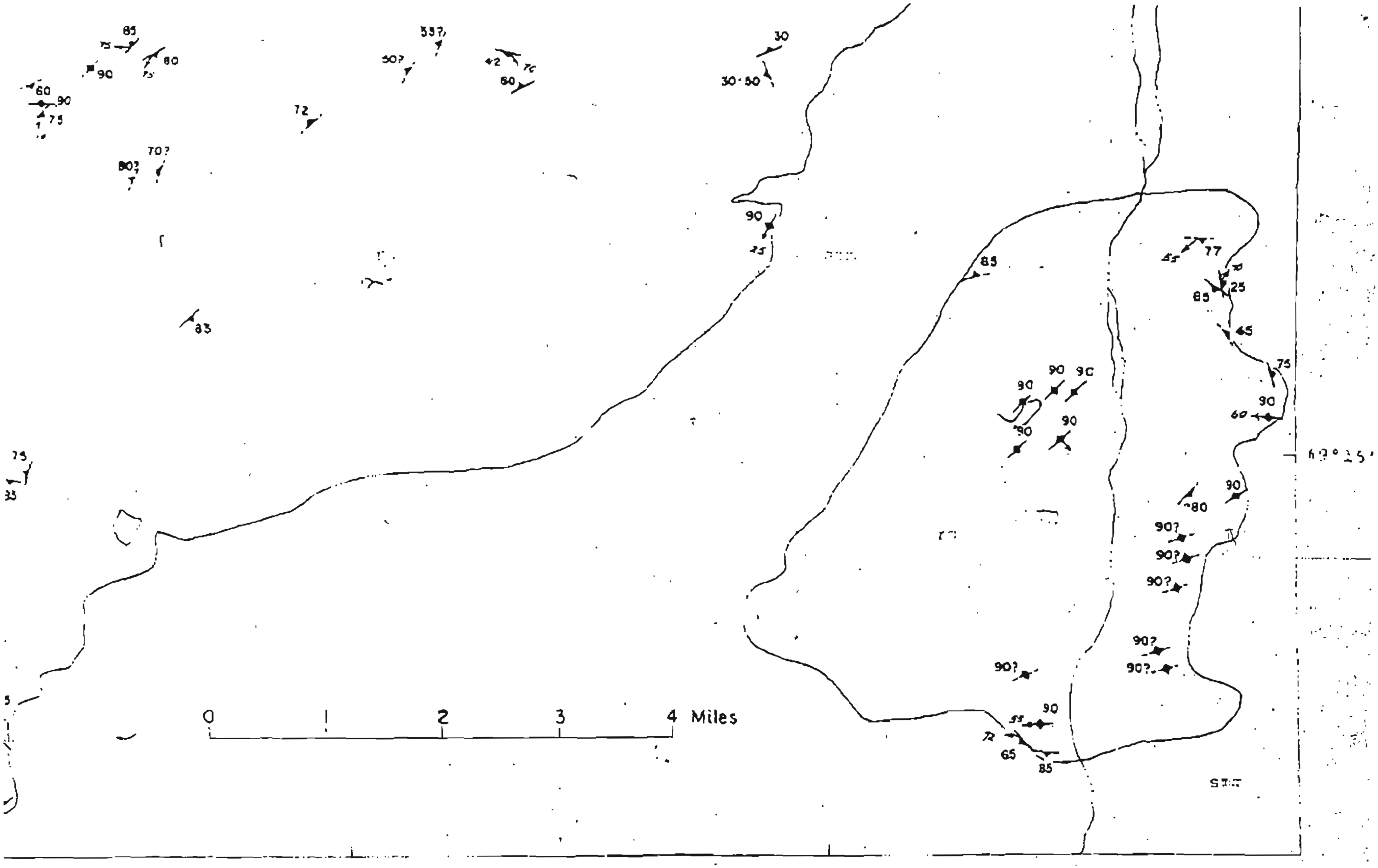
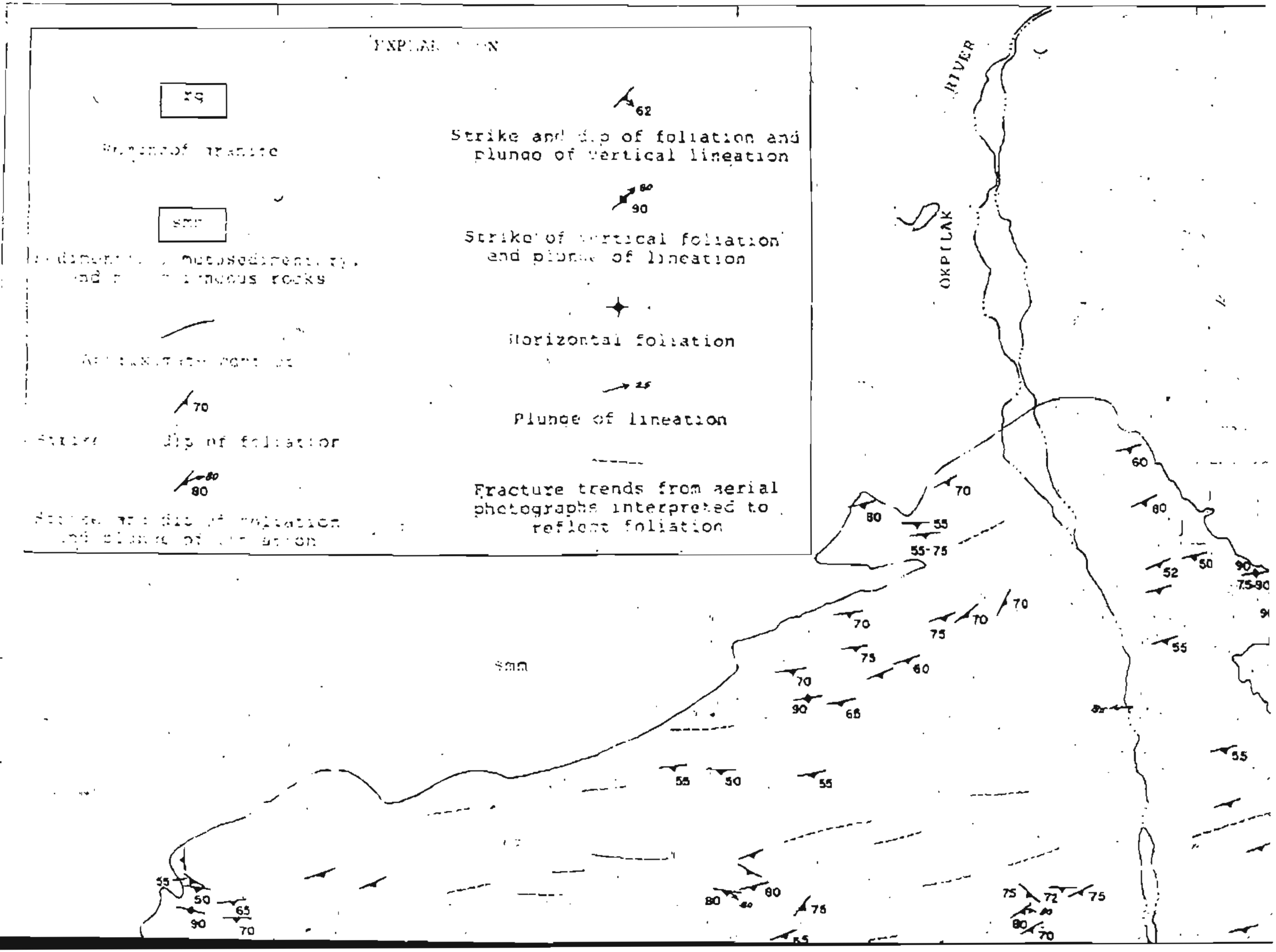
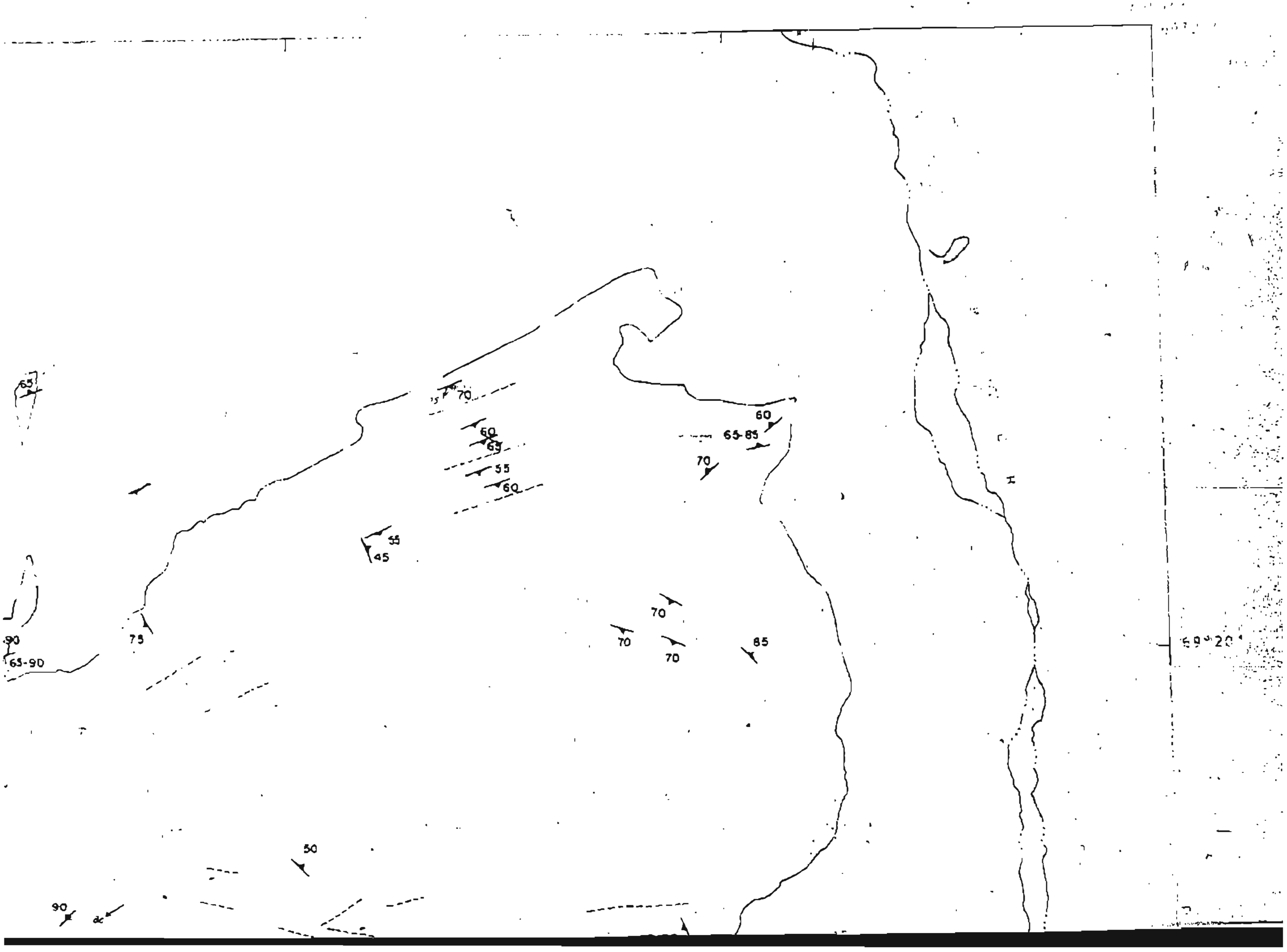


PLATE 5. MAP SHOWING FELDSPAR
ROMANZOF GRANITE, RO


0
1
2
3
4 Miles
85
75
90
80
60
90
75
70?
80?
72
50?
55?
42
70
60
30
30-50
90
25
83
75
35
85
77
45
25
85
45
75
90
60
90
90
90
90
90
80
90
90?
90?
90?
90?
90?
90?
90
55
72
65
85

EXPLANATION
Sedimentary, metasedimentary, and igneous rocks
Approximate contact
70
Strike and dip of foliation
80
80
Strike and dip of foliation and plunge of lineation
62
Strike and dip of foliation and plunge of vertical lineation
80
90
Strike of vertical foliation and plunge of lineation
Horizontal foliation
25
Plunge of lineation
Fracture trends from aerial photographs interpreted to reflect foliation
smm
OKPILAK
RIVER
70
80
55
55-75
60
80
52
50
90
75-90
70
70
75
70
70
75
60
55
70
90
68
55
50
55
55
80
80
80
75
75
72
75
80
70
55
50
90
65
70


65
70
60
65
55
60
60
65-85
70
55
45
70
70
70
85
90
63-90
75
50
90
dc
H
69°20'

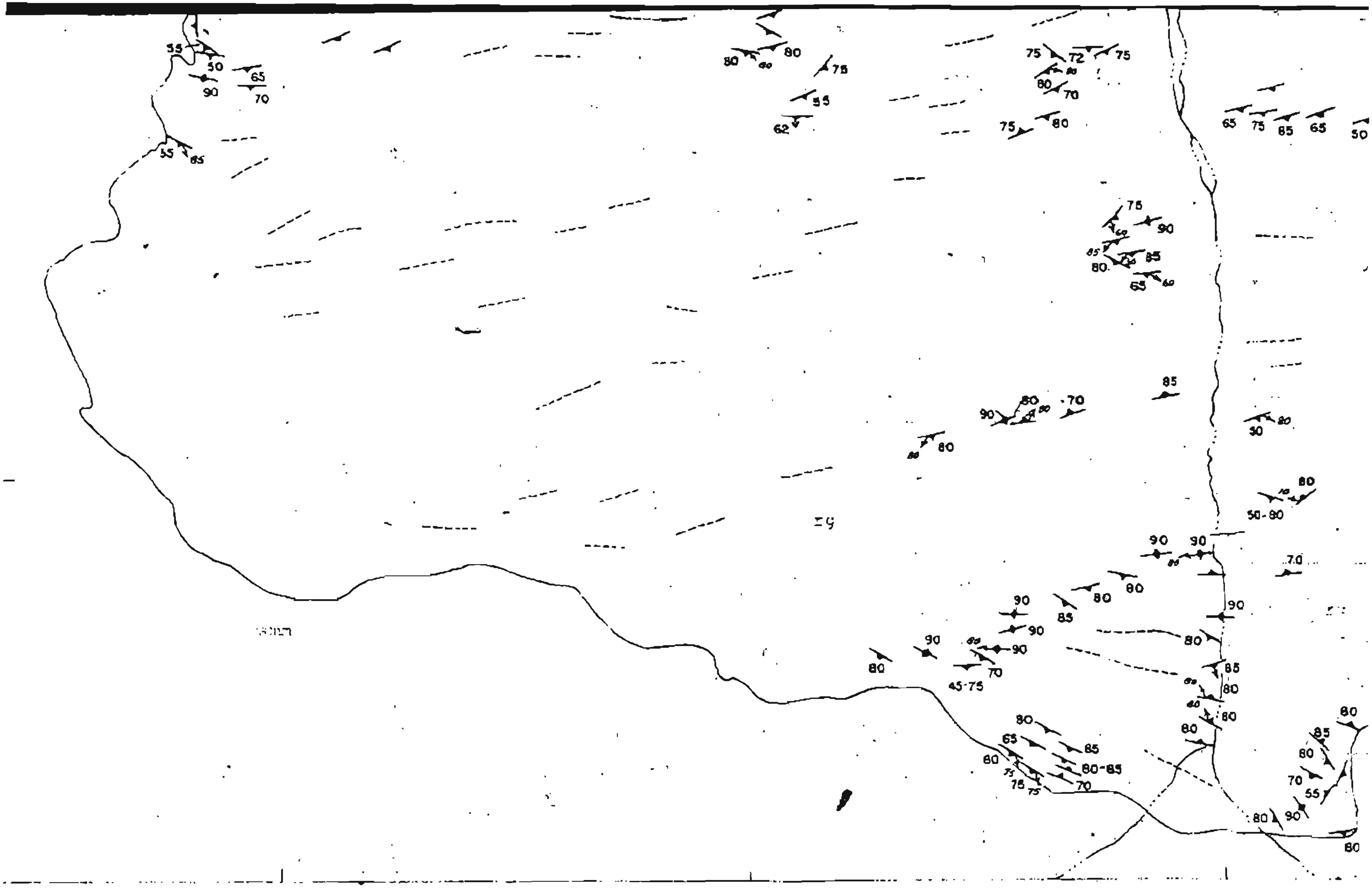
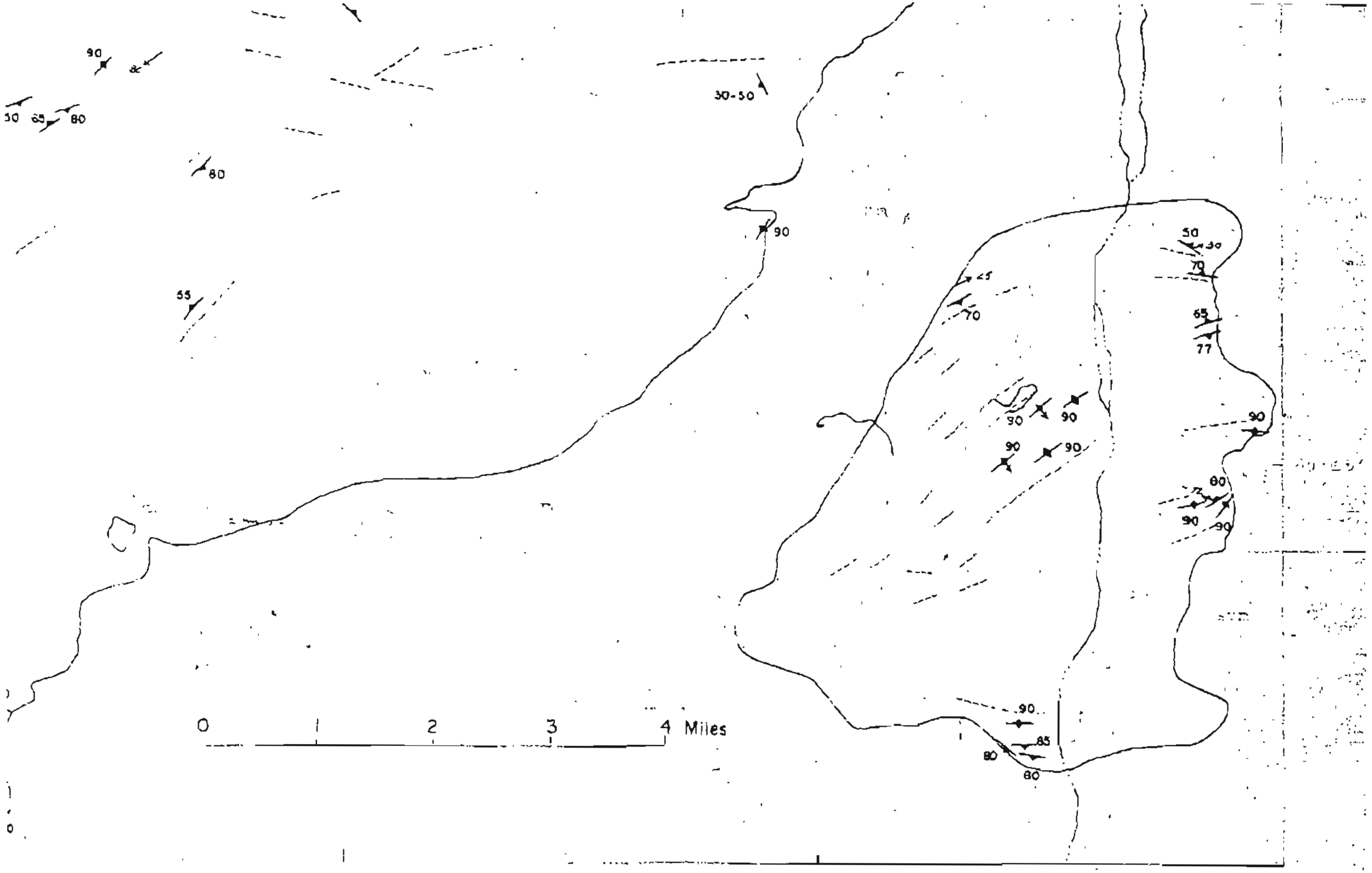


PLATE 7. MAP SHOWING [illegible]
ROMANZOF GRANITE, [illegible]


90
50
65
80
80
55
30-50
90
50
30
70
45
70
65
77
90
90
90
90
90
80
90
90
90
85
80
80
0
1
2
3
4 Miles