71-210

454

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

PETROLOGY OF THE PLUTONIC ROCKS OF WEST-CENTRAL ALASKA

By

Thomas P. Miller

Open-file report

~~1970~~
1971

This report is preliminary
and has not been edited or
reviewed for conformity with
Geological Survey standards

ACKNOWLEDGMENTS

This study was part of the U. S. Geological Survey's regional geologic mapping program in Alaska under the direction of William W. Patton, Jr., to whom I am indebted for many helpful discussions and criticisms.

Professor Robert R. Compton was my principal advisor during the study and I offer my sincere thanks for his many suggestions and helpful discussions.

Professors William C. Luth and Richard H. Jahns read the manuscript in preliminary form and offered constructive suggestions.

I thank Kenneth F. Fox, Jr., for many worthwhile discussions concerning the problems of alkaline rocks.

Finally, I am especially grateful to my wife, Shirla, for her encouragement and inspiration throughout the course of this study.

CONTENTS

CONTENTS--Continued

LIST OF TABLES

LIST OF ILLUSTRATIONS

ABSTRACT

A series of plutons in west-central Alaska defines the Hogatza plutonic belt which extends for about 200 miles in an east-west direction from the northeastern Seward Peninsula to the Koyukuk River. The plutonic rocks have an aggregate area of about 1,200 square miles and their composition, distribution, and possible petrogenesis are discussed for the first time in this report.

Field, petrographic and chemical data supported by K/Ar age dating indicate the plutonic rocks are divisible into two suites differing in age, location, and composition. The western plutons are mid-Cretaceous (~100 m.y.) in age and consist of a heterogeneous assemblage of monzonite, syenite, quartz monzonite. Associated with these granitic rocks is a group of alkaline subsilicic rocks that form a belt of intrusive complexes extending for a distance of at least 180 miles from west-central Alaska to the Bering Sea. The complex at Granite Mountain shows a rare example of zoning from an alkaline rim to a quartz-bearing core. The occurrence of a similar complex at Cape Dezhnev on the easternmost tip of Siberia suggests the alkaline province may extend into Siberia. The easternmost plutons are Late Cretaceous (~80 m.y.) in age and composed primarily of granodiorite and quartz monzonite similar to calc-alkaline plutons found throughout the North America Cordillera.

The plutons are epizonal and intrude deformed but unmetamorphosed Lower Cretaceous andesitic volcanics and volcanic graywacke which constitute the highly mobile Yukon-Koyukuk volcanogenic province of west-central Alaska. No older rocks have been found within the confines of this vast tract; the occurrence of a bounding ophiolite sequence has lead to the suggestion that the province was formed by large-scale rifting and is underlain by oceanic crust.

The possibility of no juvenile sialic crust over much of the area suggests that the potassium-rich magma now represented by the alkaline rocks originated in the mantle. The distribution of the alkaline rocks appears to be related to regional structural features, particularly the boundary between the Mesozoic volcanogenic province of west-central Alaska and the thrust-faulted province of metamorphic-plutonic and sedimentary rocks of Paleozoic and Precambrian age that forms the eastern Seward Peninsula. This boundary may have been a zone of structural weakness along which alkaline magma was generated. Modal and chemical trends suggest that the potassium-rich magma influenced the composition of more granitic magmas forming at higher levels. The latter may have been forming as a result of anatexis of andesite and mixing of mantle-derived mafic magma. The result is the heterogeneous assemblage of generally potassium-rich plutonic rocks that forms the west end of the Hogataza plutonic belt.

The loci of magmatism in west-central Alaska shifted east in Late Cretaceous time and the eastern plutons show only local signs of potassium enrichment. They are compositionally homogeneous and differences within plutons appear due to local contamination.

INTRODUCTION

GENERAL REMARKS

A belt of Mesozoic plutons of diverse composition, known as the Hogatza plutonic belt, crops out over a large part of west-central Alaska (fig. 1) but has received little petrologic attention until the present study. There are 16 principal intrusive bodies in this belt and they range in size from a few square miles to over 300 square miles, with an aggregate area of about 1,200 square miles. The plutonic rocks range from calc-alkaline granodiorite and quartz monzonite in the east to a suite of monzonite and syenite, quartz monzonite, and alkaline subsilicic rocks in the west. The present study entailed reconnaissance mapping of all the plutons and more detailed mapping of several of the larger plutons. Petrographic, chemical, and geochronologic studies were made on many of the plutonic rocks. This work was part of the U. S. Geological Survey's investigations in Alaska.

The purposes of this report are: (1) to give the general characteristics and distribution of all the plutonic rocks, (2) to present the geology and petrology of several of the larger plutons, and (3) to discuss the possible petrogenesis of the different suites of plutonic rocks and their relationship to each other.

The part of west-central Alaska under discussion is bounded on the north by the Brooks Range, on the west by the Seward

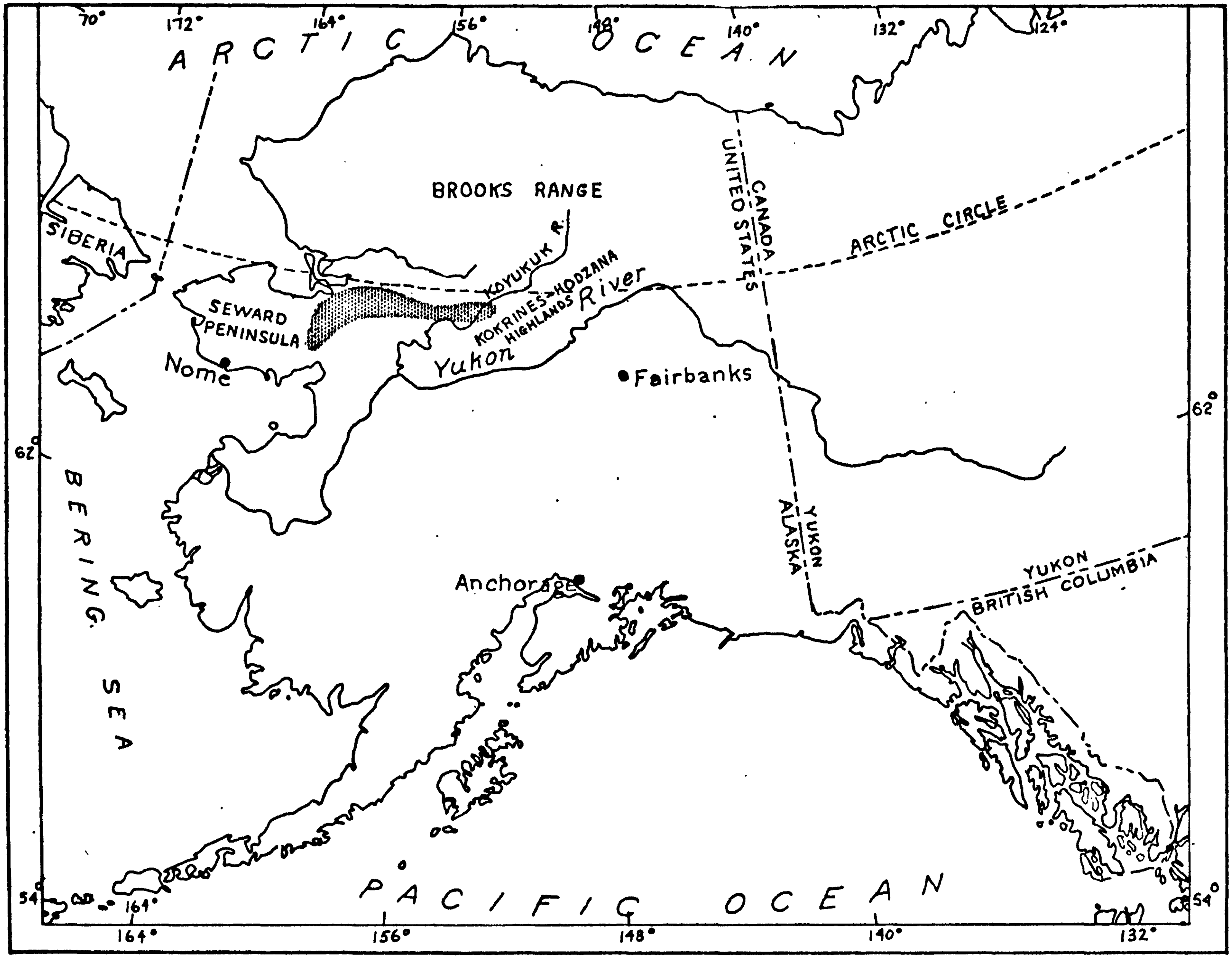


Figure 1. Index map of Alaska showing location of Hogatza plutonic belt (shaded).

Peninsula, and on the south and east by the Kokrines-Hodzana Highlands (fig. 1). It includes parts of the Hughes, Shungnak, Candle, Kateel River, Selawik and Melozitna 1:250,000-scale quadrangles.

Field work for the present study was done during the summers of 1963-1969. Helicopters were used extensively owing to the remoteness and relative inaccessibility of much of the area. Over 250 thin sections were examined and 265 modes counted. A total of 68 samples were analyzed by chemical and semiquantitative spectrographic methods at the laboratories of the U. S. Geological Survey. Twelve K/Ar dates from nine plutons were determined by geochronologists of the U. S. Geological Survey.

PREVIOUS WORK

Little mapping of the plutonic rocks of west-central Alaska was done prior to 1958 owing, at least in part, to the inaccessibility of the area. Moffit (1905) traversed most of the Kiwalik-Buckland divide in the western part of the area, and made reconnaissance maps of the Granite Mountain pluton and parts of the Hunter Creek pluton (plate 1). He recognized that the plutons are made up of a variety of rock types including granite, monzonite, and quartz diorite; he also recognized the occurrence of alkaline rocks at Granite Mountain. Smith and Eakin (1911) and Harrington (1919) briefly visited the gold and platinum placer mines of the Granite Mountain area and made improvements to Moffit's geologic map of the area.

The Indian Mountain and Zane Hills plutons in the eastern part of the region were visited briefly in the early part of this century by Smith (1913) and by Eakin (1916). Smith considered the Zane Hills and other plutons in west-central Alaska to be pre-Upper Cretaceous based on relationships he had seen northeast of Granite Mountain, namely the occurrence of granitic rock clasts in Upper Cretaceous conglomerate. Eakin presumed the Indian Mountain pluton to be Late Cretaceous or Early Tertiary in age since it intruded a unit of graywacke and mudstone which he thought to be Upper Cretaceous.

During the next 40 years no work was done in this part of Alaska with the exception of a brief report by Gault and others (1953) on the occurrence of uranium minerals in stream gravels near Granite Mountain. In 1958, members of the U. S. Geological Survey, under the direction of William W. Patton, Jr., began regional geologic mapping studies in west-central Alaska which resulted in a series of geologic maps which include the Hogatza plutonic belt (Patton, 1966; Patton and Miller, 1966; 1968; Patton, 1967; Patton, Miller and Tailleur, 1968). A preliminary report on the age and composition of the plutonic rocks was prepared by myself and others (Miller, Patton, and Lanphere, 1966).

Mineral deposits of the area have been studied in recent years as part of the Survey's program in Alaska and the results of these studies are discussed in Miller and Ferrians (1968), Miller and Elliott (1969), Miller (1969), and Elliott and Miller (1969).

PHYSIOGRAPHY

The part of west-central Alaska discussed in this report is in the Intermontane Plateaus system of Alaska (Wahrhaftig, 1965). The region consists of groups of rounded hills and low mountains surrounded and interspersed with rolling plateaus and irregular lowlands. Summits up to 4,500 feet occur in the eastern part of the area but the western part has summits no higher than 3,300 feet and is generally more subdued.

Because the entire region is only a few miles south of the Arctic Circle, most of the plutons discussed here are beyond or above timberline. There are no glaciers in the area now but large piedmont glaciers emanating from the Brooks Range in Pleistocene (Illinoian) time reached as far south as the northern flanks of many of the plutons (Coulter and others, 1965; Patton and Miller, 1968). The alkaline intrusive complexes in the southern Kobuk-Selawik Lowlands were covered by these glaciers. Parts of the Zane Hills and Wheeler Creek plutons were subjected to valley glaciation at about the same time. Most of the lowland areas are underlain by permafrost. Extensive frost action has resulted in the reduction of most outcrops to patches of angular frost-riven blocks. These are as much as several feet in length when composed of granitic rocks but as little as a few inches in length when composed of graywacke. The lack of outcrops prevents structural mapping of foliation and lineation in the plutonic rocks.

An interesting geomorphic feature in the region is the common occurrence of altiplanation terraces, which are especially well-developed in the thermally metamorphosed country rocks surrounding the plutons. In fact, the name was coined by Eakin (1916) for flat terrace-like features near Indian Mountain.

Areas of hot spring activity occur at several localities along the borders of the plutons and are shown on the geologic maps in this report.

PLUTONIC ROCKS

The plutonic rocks of west-central Alaska are divisible into two principal suites on the basis of age, location, and composition. The older, mid-Cretaceous suite is composed of a variety of rock types, generally with alkaline affinities and ranging from monzonite and syenite to quartz monzonite, and includes alkaline subsilicic rocks such as nepheline syenite and kindred rocks. The younger, Late Cretaceous suite consists primarily of calc-alkaline granitic rocks, mainly granodiorite and quartz monzonite with less abundant alaskite and hybrid rocks. The mid-Cretaceous suite constitutes the western plutons with a total area of about 650 square miles and the Late Cretaceous suite the eastern plutons with a total area of 550 square miles.

The plutons range in area from less than a square mile to more than 350 square miles (table 1). Two of the larger plutons, the Selawik Hills and the Hunter Creek, are partly covered by Quaternary basalt flows and their exposed outcrop areas of 378 and 165 square miles, respectively, are therefore minimum values. The plutons have a total surface area of about 1,200 square miles as determined by polar planimeter.

The plutons are aligned along the 200-mile-long Hogatza plutonic belt, and the larger plutons tend to be elongated parallel to this trend. In some places, roof pendants separate individual plutons at the present level of exposure, for example, the Zane

Table 1. Plutons discussed in this report

Name	Area (mi.^{2})	Modal Analyses	Chemical Analyses	K/Ar Dates
Late Cretaceous Suite				
Zane Hills pluton	180	65	8	1
Wheeler Creek pluton	271	48	6	2
Indian Mountain pluton	85	13	6	1
Mt. George pluton	6	1	--	--
McLanes Creek pluton	8	2	--	--
Totals	550	129	20	4
Mid-Cretaceous Suite				
Shiniliaok Creek pluton	30	12	2	1
Purcell Mountain pluton	40	9	--	1
Hawk River stock	5	3	--	--
Ekiek Creek Complex	5	12	3	--
Selawik Hills pluton	354	29	19	2
Hunt Creek Complex	5	14	9	1
Inland Lake Complex	12	4	2	--
Selawik Lake Complex	7	4	3	--
Hunter Creek pluton	165	11	--	1
Granite Mountain pluton	27	38	10	1
Quartz Creek pluton	3	--	--	--
Totals	653	136	48	8
Totals for both suites	1,203	265	68	12

Hills and Wheeler Creek plutons; most other plutons are probably separate to considerable depths.

CLASSIFICATION

The classifications used in this report are shown in figures 2 and 3. The classification used for the granitic rocks is that used by Bateman and others (1963, p. 13) which is modified somewhat from that proposed by Johannsen (1939). It is a modal classification based on the percentage of felsic components. Where a rock name is given to various mapped units, it is based on the average composition of the unit, even though in many cases the range in composition spreads over two or more fields.

I have used the term alkaline rock in the sense that Turner and Verhoogen (1960, p. 194) do; that is, a rock in which the alkali content is sufficiently high as compared to silica for specially alkaline minerals such as feldspathoid to appear.

The mineralogical, chemical, and textural variety of alkaline rocks has led to an excessive nomenclature and a cumbersome classification. Many are unusual rocks which do not fit readily into classifications that are familiar to most geologists. The classification I have used is a simple modal one based on the proportion of nepheline, alkali feldspar, and mafic minerals. The rock names in it were compiled from various sources (Johannsen, 1939; Parsons, 1961; Von Eckermann, 1948) and hopefully represent more or less a consensus of alkaline rock nomenclature. At least

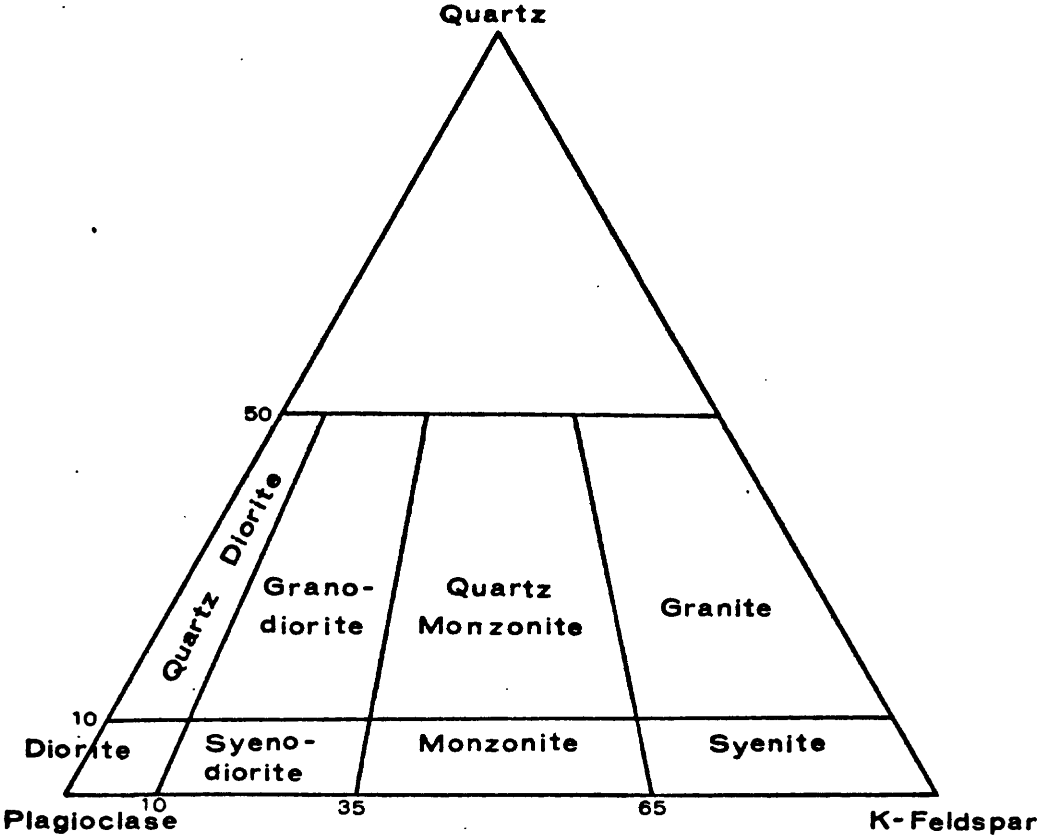


Figure 2. Classification of granitic rocks

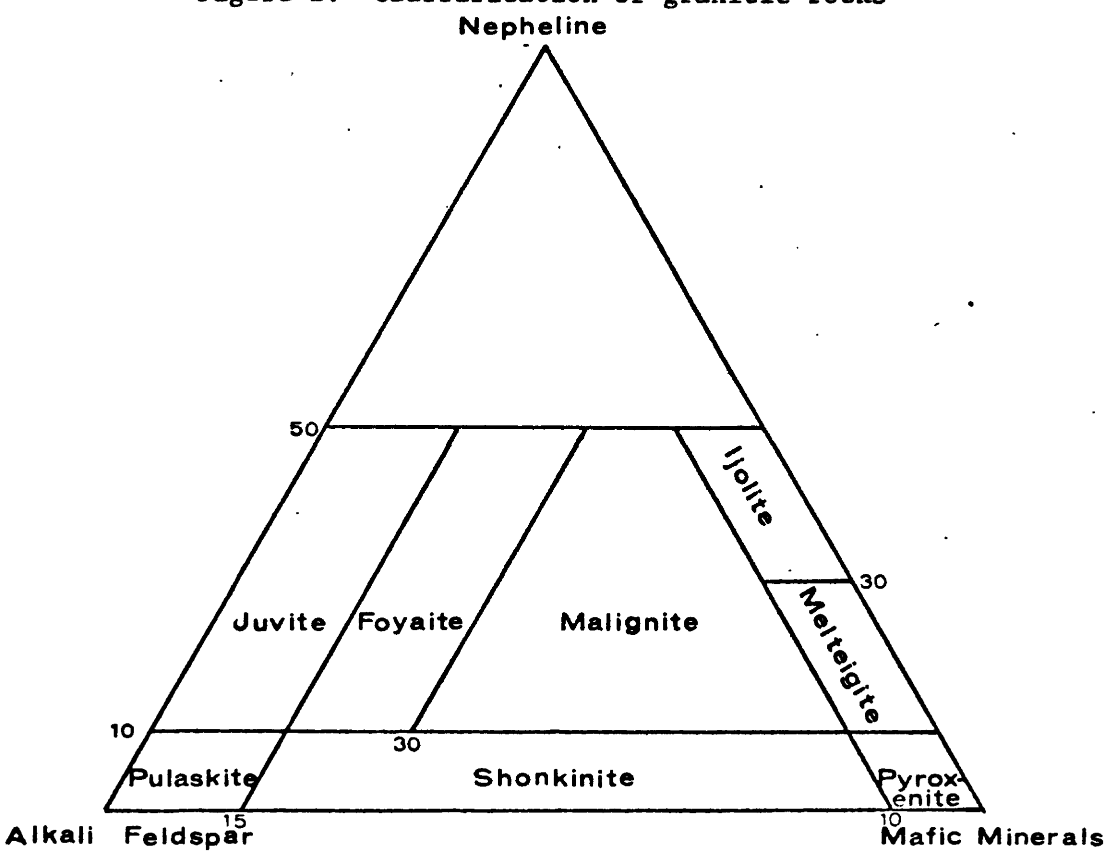


Figure 3. Classification of alkaline rocks

one of its limitations is that the plagioclase component is not a part of the classification. This is because the alkaline rocks of the western Alaska alkaline province are generally single-feldspar rocks. The scheme proved useful in mapping and in the comparison of the rocks of this province with those of other provinces.

ANALYTICAL DATA

The chemical analyses were obtained by the rapid methods described by Shapiro and Brannock (1956). Analysts were P. Elmore, G. Chloe, J. Kelsey, S. Botts, H. Smith, L. Artis, J. Glenn, and D. Taylor.

The same samples were also analyzed for minor elements by a six-step semiquantitative spectrographic method. Results of this method identify geometric intervals that have the boundaries 1.2, 0.83, 0.56, 0.38, 0.26, 0.18, 0.12, etc., and are reported as midpoints of these intervals by the numbers 1.0, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, etc. The precision of a reported value is approximately plus or minus one interval at 68-percent confidence, or two intervals at 95-percent confidence. The analyst was Chris Heropoulos.

Most of the modal analyses were determined on sawed slabs stained by sodium cobaltinitrate after the method of Bailey and Steven (1960). A total of 1,000 points were generally counted, using as large a point interval as possible on each slab, in most cases 2.0 mm or more. Thin-section modes were done chiefly on the alkaline rocks using a 1.0 mm point interval and counting 600-700 points. Ratios of mafic minerals in rocks containing pyroxene were determined by thin-section modes.

GEOLOGIC SETTING AND AGE OF THE PLUTONIC ROCKS

Most of the plutonic rocks of west-central Alaska occur along the east-trending Hogatza plutonic belt, which extends from the eastern Seward Peninsula to just east of the Koyukuk River (plate 1). The plutonic rocks intrude volcanic and sedimentary rocks of Cretaceous age which underlie most of west-central Alaska and constitute the northern part of the Yukon-Koyukuk volcanogenic province. These rocks are moderately to strongly deformed but have not been regionally metamorphosed. The province is bounded by the metasedimentary and granitic rocks of the Kokrines-Hodzana Highlands, the Brooks Range, and the Seward Peninsula (fig. 1, plate 1). The metasedimentary rocks of these bounding areas are chiefly pelitic schist, marble, and greenstone, and Paleozoic to Precambrian in age. Most of the plutonic rocks are quartz monzonite of Mesozoic age.

A belt of ophiolite-like rocks occurs along most of the mapped border of the Yukon-Koyukuk province. This assemblage of rocks includes ultramafic rocks (chiefly peridotite and dunite) at many localities, gabbro, tholeiitic pillow basalt and diabase, and bedded chert. The most common rock types are the pillow basalt and diabase. The age of this ophiolite-like unit is still uncertain but is tentatively placed at Late Triassic or Jurassic--based on correlations with similar dated rocks elsewhere in Alaska (Patton and Miller, 1970, p. 3). Patton (1970a) has suggested that large-scale rifting has occurred in west-central Alaska and these ophiolitic rocks represent oceanic material which floors the entire Yukon-Koyukuk province.

The next oldest unit in the province and the oldest rock intruded by the plutons is a thick section of marine andesitic volcanic rocks of Early Cretaceous (Neocomian) age. This unit consists chiefly of flows and fragmental rocks but includes subordinate graywacke, mudstone, and limestone. The Early Cretaceous age designation is based on the occurrence of Buchia sublaevis (Keyserling) and B. crassicolis (Keyserling) at several localities in the eastern part of the province and on K/Ar ages ranging from 134 m.y. to 120 m.y. (Patton and others, 1968; Patton, 1967; Patton and Miller, 1966). The flows and fragmental rocks are chiefly augite andesite but include basalt, dacite, and trachyandesite. Plagioclase ranging from andesine to labradorite and augite are the principal minerals. This unit forms the country rock for most of the plutons.

The andesitic volcanic rocks are overlain by graywacke and mudstone of late Early Cretaceous age. The graywacke is typically a high-rank poorly sorted type composed chiefly of plagioclase and volcanic rock detritus derived principally from the underlying volcanic rock. The graywacke is calcareous locally, particularly in the western part of the area. Overlying the graywacke and mudstone and locally gradational with them, is a section of marine and nonmarine sedimentary deposits including conglomerate and coal; these deposits occur near the edges of the province and are considered to be Late Cretaceous in age based on fossil evidence (Patton and Miller, 1966; 1968). A K/Ar date of 83 m.y. (Late Cretaceous) was obtained on biotite from an ash-fall tuff interbedded with conglomerate in the Selawik quadrangle. These rocks are thought to be correlative with the quartz pebble conglomerate intruded by the Indian Mountain pluton.

Field relations therefore show that none of the plutons of the Hogatza plutonic belt are older than Early Cretaceous and some are no older than Late Cretaceous. Field relations also indicate that there was more than one period of plutonic activity. A volcanic complex of dacite tuffs and intrusions near the Shinilikrok River lies unconformably on the Purcell Mountain and Shiniliaok Creek plutons. However, the complex is intruded by alaskite of the Wheeler Creek pluton. Other field evidence suggesting more than one intrusive episode can be seen in the occurrence of granitic clasts (Patton, 1967) in conglomerate east of the Hunter Creek pluton (plate 1). These clasts closely resemble the monzonite of the nearby Hunter Creek pluton. The conglomerate is thought by Patton (1967) to be approximately correlative with the volcanic graywacke of late Early Cretaceous (Albian) age that is intruded by the Indian Mountain and Mt. George plutons.

In support of the field data concerning the age and number of episodes of plutonism, 12 K/Ar dates were obtained on biotite and hornblende from nine of the plutons in the belt and from the volcanic complex at Shinilikrok River and are given in table 2.

The western plutons in the belt, extending as far east as the Shiniliaok Creek pluton (plate 1), have yielded K/Ar ages ranging from 107 m.y. to 97 m.y. (table 2); this time interval spans the current boundary (according to the Phanerozoic time scale of the Quarterly Journal of the Geological Society of London, 1964) of 100 m.y. separating the Upper and Lower Cretaceous. This suite of plutons will henceforth be referred to as the mid-Cretaceous (Albian-Cenomanian) suite.

The eastern plutons extend as far west as the Wheeler Creek pluton and have yielded K/Ar ages ranging from 82 to 78 m.y. (table 2). They are referred to hereafter as the Late Cretaceous suite.

The dacite volcanic complex near the Shinilikrok River is in contact with plutons of both suites and has yielded a K/Ar date of 85.2 m.y. It lies unconformably on the Purcell Mountain and Shiniliaok Creek plutons, dated at 98.6 m.y. and 99.4 m.y., respectively, and is intruded by alaskite of the Wheeler Creek pluton dated at 77.9 m.y.

The field relationships and the K/Ar dates therefore suggest that there are at least two main periods of plutonism in west-central Alaska as suggested earlier by Miller and others (1966). The discussion to follow will show that the suites differ in composition as well.

Table 2. K/Ar ages from plutonic and volcanic rocks in west-central Alaska

Location	Rock Type	Mineral	Age(m.y.)	Reference
		Late Cretaceous plutonic suite		
Indian Mountain pluton	Granodiorite	Hornblende	81.5±3.0	Patton and Miller, 1966
Zane Hills pluton	Quartz monzonite	Hornblende	81.9±3.0	Patton and Miller, 1966
Wheeler Creek pluton	Quartz monzonite	Biotite	80.6±2.0	Miller and others, 1966
Wheeler Creek pluton	Alaskite	Biotite	77.9±2.3	Unpublished[1]
		Range	77.9-81.9	
		Shinilikrok River volcanic complex		
	Dacite	Biotite	85.2±2.2	Patton and others, 1968
		Mid-Cretaceous plutonic suite		
Shiniliaok Creek pluton	Syenodiorite	Biotite	99.4±2.4	Miller and others, 1966
Purcell Mountain pluton	Quartz monzonite	Biotite	98.6±2.9	Miller and others, 1966
Selawik Hills pluton	Quartz monzonite	Biotite	97.0±3.0	Unpublished[1]
Selawik Hills pluton	Syenite	Hornblende	100±5	Miller and others, 1966
Hunt Creek Complex	Malignite	Biotite	107±2.8	Patton and Miller, 1968
Hunter Creek pluton	Monzonite	Hornblende	102±5	Patton, 1967
Granite Mountain pluton	Monzonite	Hornblende	106±3	Unpublished[1]
		Range	97.0-107.0	

[1] The analytical data for the previously unpublished ages are given in the appendix.

MID-CRETACEOUS PLUTONIC SUITE

This suite of plutonic rocks forms the west end of the Hogatza plutonic belt and has a wide range of rock types including both silica oversaturated and undersaturated varieties. It is characterized, however, by an abundance of rocks with a relatively low quartz content (generally less than 10 percent) and a high K-feldspar content. The suite includes two large bodies, the Selawik Hills pluton and the Hunter Creek pluton, and several smaller plutons at Quartz Creek, Purcell Mountain, Hawk River, and Shiniliaok Creek; these plutons are composed chiefly of monzonite, syenite, and quartz monzonite.

Associated with these granitic plutons is a group of alkaline subsilicic complexes in the Kobuk-Selawik Lowlands, at Granite Mountain, and in the Darby Mountains.

The plutons composed chiefly of granitic rocks are discussed first, followed by a discussion of the alkaline rocks of the suite.

A. GRANITIC ROCKS

Selawik Hills pluton

General character

This discordant composite pluton is the largest body in the mid-Cretaceous suite and has an exposed area of about 350 square miles. This is a minimum figure since the southern and much of the eastern parts of the pluton are overlain by Quaternary basalt flows (plate 2). The pluton extends about 45 miles in an east-west direction and underlies most of the Selawik Hills. The pluton is bounded on the north by an east-west fault zone marked by the prominent scarp-like front of the Hills.

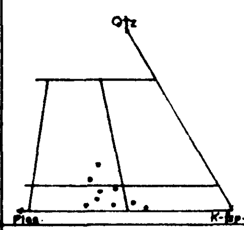
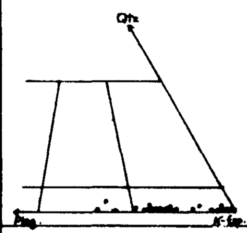
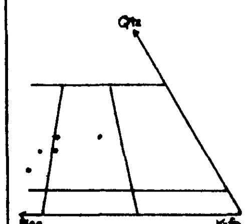
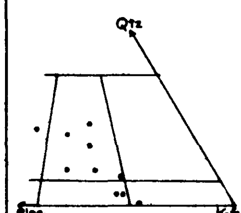
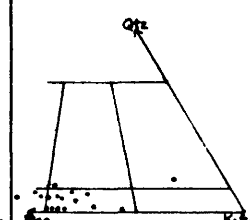
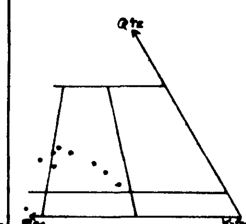
Three main units have been mapped in the pluton: (1) monzonite and syenite; (2) gneissic syenite, much of it hybrid in origin; and (3) fine-grained quartz monzonite. Potassium-argon ages of 100 m.y. have been obtained on hornblende from the gneissic syenite and 97 m.y. from the fine-grained quartz monzonite (table 2). A petrographic summary of the suite is included in table 3.

Andesitic volcanic rocks of Early Cretaceous age form most of the country rock except in the northwest where the pluton partially encloses 12 square miles of high-grade metasedimentary rocks. The andesitic country rock is thermally metamorphosed to hornblende hornfels facies near the contact and grades into albite-epidote hornfels facies further away. Most of the pluton is fault bounded; where it is not, the contact with the andesite is sharp and steeply dipping.

Petrography

Monzonite and gneissic syenite.--The west end of the pluton is composed predominantly of a pink to orange, fine- to medium-grained monzonite but includes some quartz monzonite and syenite. Interstitial modal quartz is common in most of the unit although generally less than 10 percent of the rock. The texture ranges

Table 3. Petrographic summary of some of the granitic plutons of the mid-Cretaceous plutonic suite.

		Selowik Hills pluton			Hunter Creek pluton	Shiniliaok Creek Pluton	Purcell Mountain pluton
Lithology of mapped units		monzonite, quartz monzonite	gneissic syenite	quartz monzonite	quartz monzonite, monzonite	monzonite, syenodiorite	quartz monzonite
Color index		7-20	15-40	5-10	5-20	15-20	5-15
COMPOSITION	Mafic minerals	hornblende, clinopyroxene, biotite	hornblende, clinopyroxene	biotite	hornblende, clinopyroxene	biotite, clinopyroxene	hornblende, biotite
	Plagioclase composition	oligoclase (An_{20-28})	oligoclase	Sodic oligoclase	oligoclase-andesine (An_{25-35})	andesine (An_{34-40})	andesine (An_{35-40})
	Ubiquitous accessories	apatite, sphene, magnetite, allanite					
	Other accessories	fluorite	fluorite, zircon		zircon	tourmaline, zircon	zircon
	Modal composition						
TEXTURE	Grain size	fine to medium	medium to coarse	fine	medium	medium	medium
	Fabric	allotriomorphic granular to porphyritic and trachytoid	trachytoid to gneissic	gneissic - cataclastic along northern border; hypidiomorphic elsewhere	cataclastic	hypidiomorphic and equigranular	hypidiomorphic and equigranular to porphyritic
	Plagioclase with oscillatory normal zoning	rare	rare	faint	rare	faint	common
Characteristic feature		Pink to orange color	gneissic and trachytoid fabric	fine grain size	cataclastic fabric	low quartz content, abundant biotite	scattered feldspar phenocrysts

from medium grained, allotriomorphic granular (fig. 4) to porphyritic and locally trachytoid.

The north-central and northeastern parts of the pluton consist of syenite and monzonite marked by a characteristic gneissic and locally trachytoid texture. Compositionally, quartz is absent, large perthitic K-feldspar phenocrysts up to 3 inches long are abundant, and the plagioclase content is relatively low. The mafic mineral content is high, up to 40 percent locally, and clinopyroxene is at least as abundant as hornblende, if not more so.

The composition changes considerably over short distances, particularly the mafic mineral content. Much of the gneissic syenite near the northern border of the pluton appears to be hybrid in origin. The magma in this area appears to have been contaminated by reaction with andesitic country rock. Indeed, some of the unit is probably metasomatized andesite. The end result of this contamination and metasomatism is a mesocratic syenite that consists entirely of large K-feldspar phenocrysts in a "groundmass" of hornblende and pyroxene (figs. 5 and 6).

The range in modal composition of the monzonite and gneissic syenite is shown in a plot of representative modes (table 3). A trend from relatively quartzose rocks to quartz-free, K-feldspar rich rock is apparent. Most of the K-feldspar rich rocks are in the gneissic hybrid syenite.

The texture of the gneissic syenite also changes considerably over short distances but consistently shows a planar flow

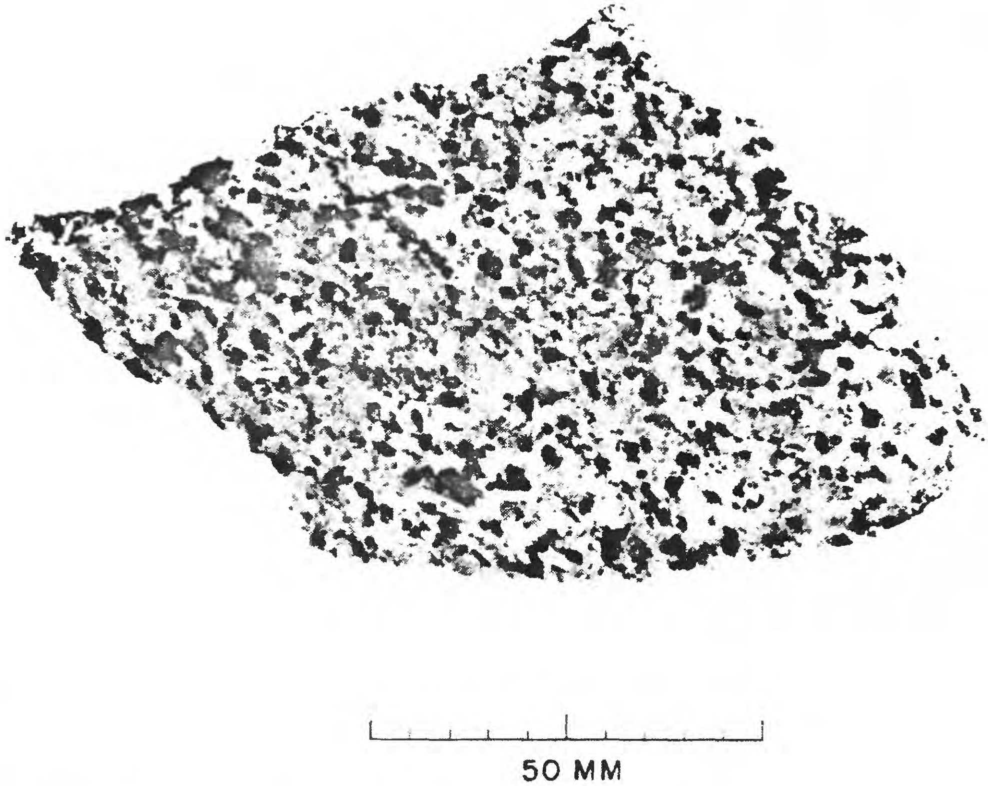


Figure 4. Monzonite from the western Selawik Hills pluton.

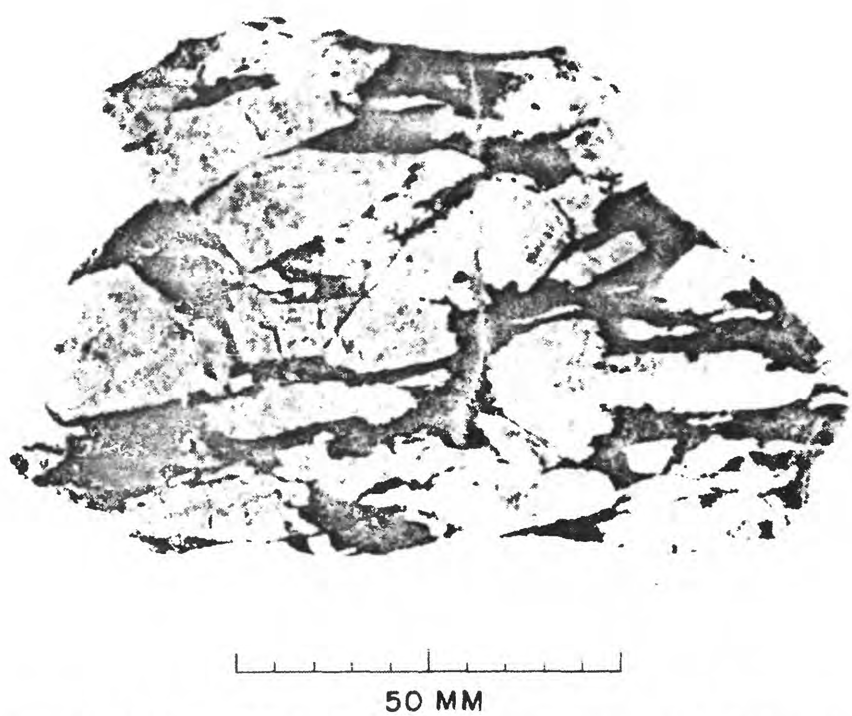


Figure 5. Hybrid syenite from the north-central Selawik Hills pluton.

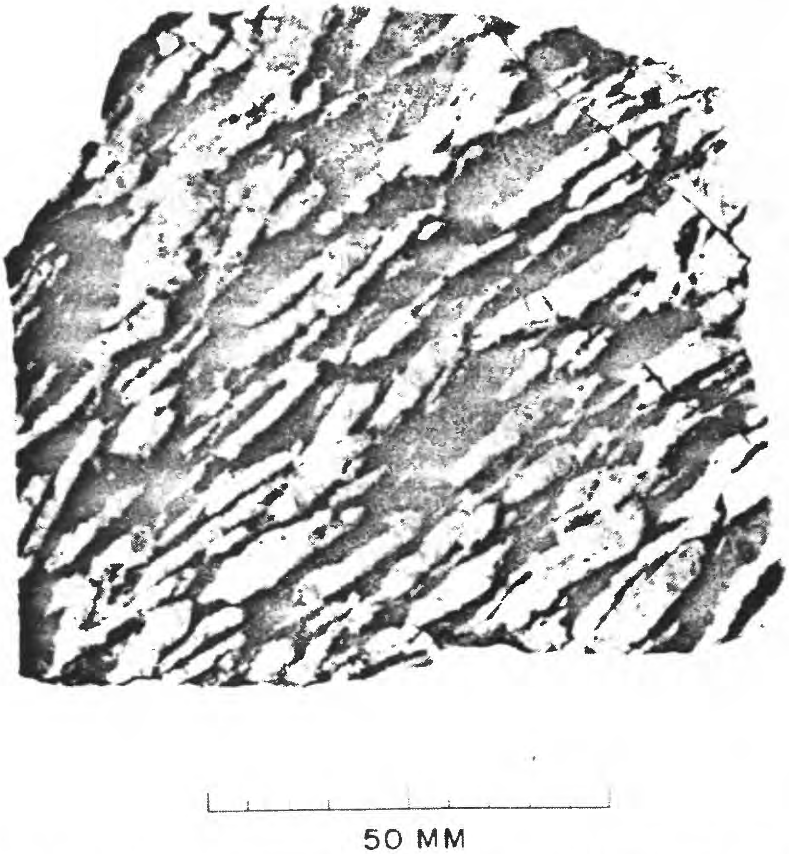


Figure 6. Gneissic syenite from the northern Selawik Hills pluton showing well-developed planar flow structure.

Figure 7. Gneissic syenite from the Selawik Hills pluton; note "drag" of planar flow structure along margin of aplite dike.

structure, either gneissic or trachytoid. These textural changes appear to be gradational. The lack of rock actually in place prohibits the determination of attitudes on the planar flow features. However, the predominance of the planar fabrics in the northern part of the pluton near the bounding fault zone suggests that they may be due to movement along the fault during the intrusion of the pluton.

The change in composition and texture between the gneissic syenite and the monzonite is a gradual one and the contact between these units shown in plate 2 should be regarded only as an approximate line north of which the rock has an oriented fabric and consists chiefly of gneissic syenite.

Numerous screens of metamorphic mafic rocks occur in the gneissic syenite generally along prominent lineaments. These are typically pyroxene-scapolite-plagioclase-sphene gneiss, scapolite-diopside marble, and amphibolite. The scapolite composition is estimated at about Me_{70} from X-ray patterns (Burley and others, 1961). The location of several of these bodies is shown in plate 2 but there are undoubtedly more of them in this part of the pluton.

Dike-like bodies of generally gneissic or trachytoid nepheline syenite are common in the gneissic syenite and probably are more abundant than are actually shown in plate 2. These alkaline rocks are typically melanite-bearing juvite and foyaite.

Non-gneissic aplite dikes also cut the gneissic syenite. In some places, the planar flow structure of the gneiss is curved along the contact with the aplite (fig. 7). This could be due either to intrusion of the aplite while the syenite was still in a viscous state or by intrusion of the aplite along a fault.

Quartz monzonite.--Most of the eastern half of the pluton is underlain by a fine-grained biotite quartz monzonite. The texture in the northern part of the unit is gneissic and cataclastic but changes to hypidiomorphic and equigranular in the southern half.

Compositionally the quartz monzonite is a homogeneous leucocratic rock; representative modes are plotted in table 3 and illustrate the higher quartz content relative to the other units in the pluton.

The quartz monzonite has an intrusive contact with the Lower Cretaceous andesitic country rock. The nature of the contact with the gneissic syenite and monzonite is less clear. The poor exposures and extensive frost action mask the actual contact zone and mutual relationships cannot be observed. However, the change in lithology is fairly abrupt and the contact appears to be sharp. A possible difference in the origin of the oriented texture in the two units may shed some light on their relative ages. The cataclastic and gneissic texture in the northern part of the quartz monzonite appears to be a post-crystallization feature. Evidence of this is the mosaic of granulated and crushed quartz grains with sutured boundaries suggesting the quartz monzonite had crystallized prior to deformation. The quartz also shows an alinement of the c-axis of individual grains roughly parallel to the foliation of the biotite. The occurrence of this cataclastic texture near the east-west fault zone along the north front of the Selawik Hills suggests it was caused by movement along this fault zone. The planar flow fabric in the gneissic syenite, however, appears to have been developed during intrusion. The common alinement of euhedral K-feldspar phenocrysts in a groundmass of mafic minerals together with a lack of granulated grains and sutured grain contacts suggest the deformation took place while the syenite was still in a viscous state. If the cataclastic texture in the quartz monzonite and the planar flow structure in the gneissic syenite are both related to the same movements along the east-west fault zone, then the quartz monzonite is the older unit.

Chemistry

Chemical analyses were obtained on 17 samples of monzonite and gneissic syenite and two samples of quartz monzonite; these analyses are given in table 4 along with norms, modes, and minor element analyses. The samples are thought to be representative of the quartz monzonite and to cover the range in composition of the monzonite and gneissic syenite. An analysis of a nepheline syenite dike is also included.

The analyses show the relatively low SiO_2 content of the monzonite and gneissic syenite. The range is from 53.8 to 66.1 percent but is generally less than 60 percent in the gneissic syenite. Alumina is commonly over 16 percent, and as high as

Teble 4. Chemical data of the Selawik Hills pluton

Repid rock chemical anelyees (weight percent)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
SiO_2	66.1	63.3	61.7	60.5	59.5	59.4	57.8	57.2	59.1	57.5	56.4	61.5	55.4	53.8	59.7	54.8	59.1	73.9	71.4
Al_2O_3	16.2	15.7	15.6	17.3	16.7	16.6	16.9	16.4	17.7	15.9	14.5	17.5	16.0	13.4	17.8	15.6	18.4	14.7	15.5
Fe_2O_3	1.3	1.6	1.9	2.0	2.3	1.9	2.1	1.6	1.8	2.0	2.3	1.8	2.8	3.1	2.0	2.8	1.7	.73	.64
FeO	1.6	2.6	2.5	2.4	2.1	2.4	3.2	4.0	2.6	3.4	3.7	2.4	3.9	4.2	2.4	3.2	2.1	.52	.60
MgO	.72	2.3	2.4	1.6	1.5	1.8	2.9	3.6	1.9	3.0	3.2	1.6	3.2	3.8	1.5	2.5	1.6	.16	.35
CaO	2.3	4.0	3.3	3.9	4.1	4.9	6.0	6.2	4.2	5.8	5.8	4.0	5.4	10.2	3.1	7.9	4.1	1.3	1.8
Na_2O	3.9	3.5	3.7	3.9	3.4	3.5	3.3	3.3	4.3	3.1	3.4	3.6	3.0	2.2	3.1	4.0	3.2	3.8	4.2
K_2O	5.6	4.9	5.4	6.7	7.9	7.5	5.9	4.8	5.7	5.9	5.7	5.9	6.7	5.5	8.4	5.8	7.3	4.2	3.7
H_2O-	.08	.11	.19	.09	.06	.08	.10	0.0	.11	.10	.13	.10	.11	.20	.16	.04	.08	.11	.09
H_2O+	.49	.64	.91	.35	.50	.42	.59	.80	.51	.67	.87	.51	.88	.53	.51	.75	.89	.35	.53
TiO_2	.58	.75	.78	.75	.87	.63	.75	.96	.78	.91	.97	.71	.97	1.0	.17	1.4	.41	.11	.18
P_2O_5	.18	.32	.32	.25	.38	.34	.46	.42	.25	.36	.49	.26	.58	.69	.26	.44	.20	.02	.03
MnO	.07	.09	.09	.09	.09	.09	.09	.10	.09	.11	.11	.11	.11	.15	.11	.20	.11	.03	.04
CO_2	<.05	<.05	.98	<.05	<.05	<.05	<.05	<.05	.90	1.0	<.05	<.05	<.05	1.0	.14	<.05	.09	<.05	1.0
Sum	100	100	100	100	99	100	100	99	100	100	100	100	99	100	100	99	99	100	100

Semiquantitetive spectrographic analysee (ppm)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
B	10	15	30	10	10	50	---	50	---	10	---	15	20	30	7	---	10	20	10
Ba	1000	2000	1500	1500	3000	2000	3000	2000	2000	2000	2000	1500	3000	3000	1500	15000	3000	700	1500
Be	10	7	10	7	7	7	2	7	5	7	3	7	5	15	10	7	5	5	3
Co	5	15	15	10	10	10	20	20	10	20	30	10	20	30	10	20	10	---	2
Cr	5	50	50	20	10	30	50	100	20	100	50	20	30	50	15	30	30	---	1
Cu	7	15	30	30	30	7	5	20	20	10	30	7	50	70	20	70	15	3	2
La	150	100	150	100	200	150	150	150	150	200	100	100	200	200	150	200	300	30	---
Nb	50	30	50	50	50	15	7	50	50	50	15	50	20	20	70	70	20	15	7
Ni	3	50	50	15	15	15	50	70	20	70	50	15	30	50	10	15	15	15	---
Pb	70	30	100	100	100	150	100	70	100	100	70	100	150	70	100	70	300	50	50
Sc	3	15	10	7	10	10	7	15	7	10	15	7	15	20	7	15	10	---	---
Sn	10	15	15	10	7	7	7	10	7	10	7	10	7	15	10	10	---	---	---
Sr	1000	1500	1500	1500	2000	3000	3000	2000	1500	2000	2000	1500	3000	3000	2000	5000	2000	500	1500
V	30	100	100	100	100	150	150	150	100	150	200	100	200	200	150	150	100	10	10
Y	50	50	70	70	50	50	30	70	50	70	50	50	70	70	70	50	50	10	15
Zr	500	500	500	300	200	300	70	300	700	700	150	500	200	500	500	300	300	150	150
Ce	200	150	200	200	300	200	150	200	200	300	200	200	300	500	300	500	700	---	---
Ga	30	30	20	30	15	20	20	20	20	20	20	3	20	20	20	15	15	15	15
Yb	3	5	5	7	3	3	2	5	5	5	3	5	5	7	5	3	3	1	1
Nd	70	70	100	100	200	100	100	100	100	150	100	100	150	200	100	200	300	---	---

Table 4--continued

CIPW norms (weight percent)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
q	16.3	13.2	11.7	3.1	1.7	0.4	1.5	2.8	2.9	4.0	1.4	7.8	---	1.7	1.6	---	2.2	32.8	31.3
or	33.6	29.2	32.3	39.8	47.2	44.7	35.1	28.8	33.9	35.2	34.9	35.1	40.4	32.8	50.0	34.7	43.9	25.0	22.0
ab	33.5	29.9	31.7	33.2	29.1	29.9	28.1	28.3	36.6	26.5	29.8	30.7	25.9	18.8	26.4	24.2	27.5	32.3	35.7
an	10.3	12.8	8.2	10.0	7.1	7.5	14.0	16.0	12.2	12.2	7.7	14.3	10.6	10.5	9.9	7.6	14.5	6.4	2.4
wo	.03	2.1	---	3.3	4.5	6.2	5.4	5.2	0.6	3.4	7.8	1.7	---	12.4	1.2	12.2	1.8	---	---
en	1.8	5.8	6.1	4.0	3.8	4.5	7.3	9.1	4.8	7.5	8.3	4.0	5.4	9.6	3.8	6.3	4.1	0.4	0.9
fs	1.1	2.4	1.9	1.7	0.7	2.0	3.1	4.7	2.2	3.3	3.6	2.0	4.9	3.8	1.8	1.6	2.0	0.2	0.4
fo	---	---	---	---	---	---	---	---	---	---	---	---	2.1	---	---	---	---	---	---
fa	---	---	---	---	---	---	---	---	---	---	---	---	1.1	---	---	---	---	---	---
mt	1.9	2.3	2.8	2.9	3.4	2.8	3.1	2.4	2.6	2.9	3.5	2.6	4.1	4.5	2.9	4.1	2.5	1.1	0.9
il	1.1	1.4	1.5	1.4	1.7	1.2	1.4	1.8	1.5	1.7	1.9	1.4	1.9	1.9	1.4	2.7	0.8	0.2	0.3
ap	0.4	.8	0.8	0.6	0.9	.8	1.1	1.0	0.6	0.9	1.2	0.6	1.4	1.7	0.6	1.1	0.5	.05	.07
cc	---	---	2.3	---	0.1	---	---	---	2.1	2.3	---	---	---	2.3	0.3	0.2	0.2	---	2.3
c	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	1.6	3.7
ne	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	5.5	---	---	---
DI	83.4	72.3	75.7	76.1	78.0	75.0	64.7	59.9	76.4	65.7	76.1	73.6	66.3	53.3	78.0	64.4	73.6	90.1	89.0

Modes (volume percent)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Quartz	12.0	7.1	5.6	0.7	---	---	0.4	0.2	---	---	---	4.2	---	---	1.2	---	---	30.1	24.6
Plagioclase	37.1	28.5	30.7	19.0	0.1	8.3	16.1	34.2	27.1	4.0	18.3	35.3	10.8	11.3	22.8	---	20.8	29.7	25.9
K-feldspar	44.2	46.6	41.6	58.0	86.2	71.6	57.0	38.4	54.1	69.8	52.1	45.2	62.3	46.3	59.5	56.9	65.7	39.3	46.3
Mafic minerals	6.7	17.8	22.5	20.0	13.7	20.1	26.5	27.2	18.8	26.2	29.6	15.3	26.5	41.3	15.9	31.7	13.2	0.9	3.2
(Hornblende)	(5.0)	(16.0)	(22.5)	(14.2)	(5.7)		(13.3)	(26.1)	(16.9)							(0.3)	(12.9)	---	---
(Pyroxene)	---	(0.4)	---	(5.6)	(8.0)		(11.4)	(1.1)	(1.9)							(26.8)	(0.3)	---	---
(Biotite)	(1.7)	(1.4)	---	(0.2)	---		(1.8)	---	---							(1.8)	---	(0.5)	(3.2)
Nepheline	---	---		---	---		---	---	---							11.6	---		
CI	7	18	23	20	14	20	27	27	19	26	30	15	27	41	16	32	13	1	3

Description of Analyzed Rocks

1 Quartz monzonite
2 Porphyritic monzonite
3 Monzonite
4 Monzonite
5 Syenite
6 Trachytoid syenite
7 Trachytoid syenite
8 Monzonite
9 Gneissic syenite
10 Gneissic syenite
11 Gneissic syenite
12 Gneissic monzonite
13 Trachytoid syenite
14 Trachytoid melano-syenite
15 Genissic syenite
16 Trachytoid foyaite
17 Syenite-Ekiek Creek complex
18 Fine-grained quartz monzonite
19 Fine-grained quartz monzonite

18 percent. Iron and magnesia increase considerably in the gneissic syenite and reflect the increase in mafic mineral in the unit.

Of particular interest is the high K_2O content, which ranges from 4.8 to 8.4 percent and averages 6.2 percent. The K_2O/Na_2O ratio is also high, being greater than 1.0 in all analyzed specimens and greater than 2.0 in several. The Ba content in foyaite is very high at 1.5 percent.

The analyses of the two samples of undeformed quartz monzonite show a high SiO_2 content of 73.9 and 71.4 percent and are similar to Nockolds (1954) average biotite quartz monzonite, although with somewhat less FeO and MgO.

All but one of the specimens of monzonite and gneissic syenite contain normative quartz; however, this is generally less than 5 percent and thus most of the specimens appear to be silica saturated. The normative salic components of all specimens except the foyaite are plotted in figure 8. The plot shows a trend similar to the modes but is off-set more toward the plagioclase apex. This difference probably results from solid solution of albite in K-feldspar; the modes were measured from stained slabs and perthite was counted as K-feldspar.

Associated high-grade
metamorphic rocks

A fault-bounded assemblage of high-grade metamorphic rocks 8 miles long by 2 miles wide occurs along the northwest edge of the Selawik Hills pluton. Included in this group of rocks are

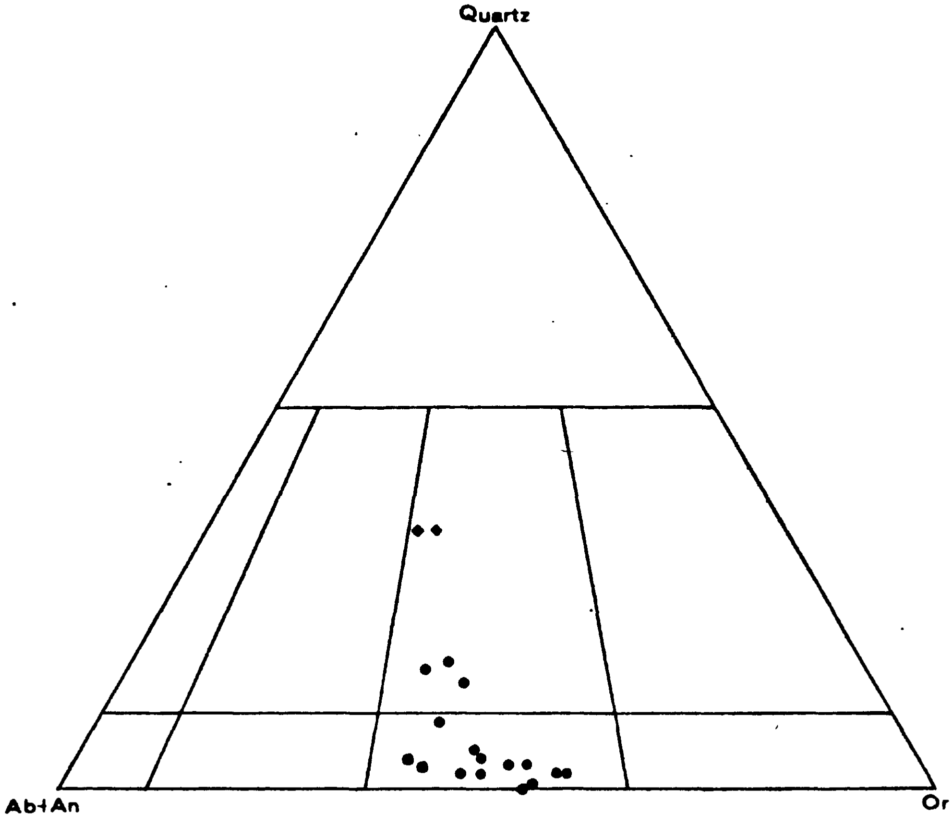


Figure 8. Normative trends of the granitic rocks of the Selawik Hills pluton: ◆, biotite quartz monzonite; ●, monzonite and gneissic syenite.

fine-grained gneiss, schist, marble, and calc-silicate rock along with intrusive rocks ranging from alaskite to gneissic nepheline syenite.

These high-grade metamorphic rocks have been tentatively correlated by Patton and Miller (1968) with an assemblage of calcareous graywacke, mudstone, calcarenite, and limestone conglomerate 50 miles to the north across the Kobuk-Selawik Lowlands in the Waring Mountains. These sedimentary rocks are unmetamorphosed and estimated to be 6,000 to 10,000 feet thick; their age is probably Early Cretaceous (Albian) based on locally abundant marine mollusks, according to D. L. Jones (Patton and Miller, 1968). The correlation is based on (1) similarity of conglomerate clasts, (2) similarity of bulk lithologic composition, and (3) the absence of similar conglomeratic carbonate rocks in other parts of the stratigraphic column in west-central Alaska.

The metamorphic rocks include quartzo-feldspathic and pelitic types as well as calcareous and mafic rocks. The quartzo-feldspathic and pelitic rocks are fine-grained paragneiss characterized by the assemblage quartz-plagioclase-biotite-sillimanite-almandine±orthoclase±spinel. Cordierite and muscovite are notably absent.

The calcareous rocks are now marble and calc-silicate rock characterized by various combinations of calcite, diopside, quartz and scapolite, some with garnet. Wollastonite and tremolite were not observed. Foresterite and spinel are observed in silica-deficient rocks. Quartz commonly occurs as relict detrital grains along with clasts of granitic and mafic rock.

Mafic rocks occur as clasts of amphibolite in calcareous metaconglomerate, as thin layers, and as gneisses along fault slices in the pluton proper. Typical assemblages found in the amphibolite clasts are hornblende-labradorite (An_{60})-diopside-sphene. Pyroxene-scapolite (Me_{60-70})-sphene gneiss occurs along the fault slices in the pluton.

Several assemblages and minerals in these rocks are indicative of high temperature and pressure. The occurrence of orthoclase in place of muscovite in the pelitic rocks is thought to indicate the highest temperature subfacies of the amphibolite facies, namely the sillimanite-almandine-orthoclase subfacies (Winkler, 1965, p. 92). The pyroxene-hornfels facies is likewise indicated by the presence of this assemblage, but the presence of almandine in place of cordierite suggests higher pressures than usually expected in contact rocks. The occurrence of almandine in place of cordierite could be a function, however, of FeO/MgO. The co-existence of spinel (a green hercynite) with quartz is also indicative of high T-P conditions.

Winkler (1965, p. 93) suggests temperatures of 700°C and pressures of 6 kb might be necessary for the development of these assemblages.

The occurrence of these high-grade metamorphic rocks here is an anomaly since rocks of similar metamorphic grade have not been found elsewhere in the Yukon-Koyukuk province. Typically the country rock of the Hogatza plutonic belt is Lower Cretaceous andesitic volcanic rocks which have been thermally metamorphosed in the vicinity of the plutons but have not been regionally metamorphosed. The contact aureole generally consists of a narrow zone of hornblende hornfels facies rocks characterized by large hornblende porphyroblasts and the zone grades into albite-epidote hornfels facies rocks farther from the contact. This type of contact aureole is found in the andesite country rock around the Selawik Hills pluton. Only the fault-bounded "block" of metasediments shows the higher grade of metamorphism.

If the sediments are indeed Albian, only a relatively short time was available for deposition, metamorphism, and intrusion by the mid-Cretaceous plutonic rocks. This would seem to rule out burial to the depths usually thought necessary to develop the pressure indicated by the mineral assemblages developed. Rutland (1965, p. 136), in a study of tectonic overpressures compared appropriate experimental evidence with geologic evidence and suggested that supposed pressure conditions for stable crystallization of critical minerals could rarely be achieved by depth of burial alone. Rutland thought that tectonic overpressures of the magnitude required are unlikely and suggested chemical explanations, particularly metastable growth, for the existence of some mineral assemblages.

Apparently, mineral assemblages normally thought to be indicative of a high temperature and pressure regional metamorphic facies, or at least a deep-seated contact metamorphic environment, were developed in what may have been a shallow contact metamorphic setting. Their occurrence coincides with that part of the pluton which appears to have been subjected to deformation while still in a viscous stage; this was also the site of K-enrichment, and assimilation and metasomatism of country rock. Perhaps one or more of these factors influenced the development of this metamorphic assemblage.

The intrusive rocks found within this metamorphic unit are gneissic nepheline syenite and alaskite. The former may have been intruded early in the deformational history of this unit and the latter, the alaskite, could be the result of anatexis.

Igneous history

The Selawik Hills composite pluton, particularly the western and central parts, has had a complex and involved history and runs the gamut in composition from silica-oversaturated rocks to silica-undersaturated rocks. The relationship between the quartz monzonite in the east and the silica-saturated rocks of the remainder of the pluton is not clear but on the basis of textural differences, the quartz monzonite unit appears older. The K/Ar dates suggest that all the units are part of the same magmatic episode.

In the western Selawik Hills, quartz-bearing monzonitic magma with a rather low silica content was intruded into Lower

Cretaceous (Neocomian) andesitic volcanics in mid-Cretaceous time. In the center of the pluton and along its northern margin, the magma was enriched in potassium and was cut by potassium-rich nepheline syenite dikes. Large amounts of andesitic country rock in this same area appear to have been engulfed by the magma and contaminated it, resulting in hybrid mesocratic syenite. The northern margin of the pluton is bounded by an east-west fault zone which appears to have been active during at least the late stages of emplacement of the magma. Movement along this fault may have caused the primary planar flow structure so characteristic of the syenite in this part of the pluton.

The close spatial association of metasomatized gneissic syenite with nepheline syenite dikes in the Selawik Hills and with potassic subsilicic complexes in the Kobuk-Selawik Lowlands suggests that the metasomatism is related to the intrusion of the potassium-rich subsilicic rocks.

The Quartz Creek pluton

This poorly exposed pluton lies a few miles west of the Granite Mountain pluton near Quartz Creek (plate 1). Metamorphosed andesite between the two limbs of the pluton together with its hook-shape and location at the base of a low range of hills suggests that only the top of an otherwise concealed pluton is exposed (Miller and Elliott, 1969). The pluton intrudes Lower Cretaceous volcanic rocks; its absolute age is unknown and it is tentatively included in the mid-Cretaceous suite on the basis of geographic location only.

The pluton is composed chiefly of fine- to medium-grained quartz monzonite; the rock is leucocratic and the varietal mafic minerals are hornblende and biotite. The east limb of the pluton has been intensely altered with abundant development of tourmaline and sulfides. The quartz monzonite in this region has been tourmalinized along closely spaced fractures resulting in a "bleached" quartz-feldspar-tourmaline rock with the tourmaline concentrated along the fractures. The end product of tourmalinization is a dense fine-grained black rock composed chiefly of quartz and tourmaline with lesser amounts of sulfides. Late veins and massive bodies of calcite cut the altered intrusive rock. The andesitic country rock has also been pervasively altered. Galena, sphalerite, arsenopyrite, and pyrite occur in both the tourmalinized rock and in the carbonate bodies.

Hunter Creek pluton

This large pluton lies immediately to the southwest of the Selawik Hills pluton and is poorly exposed along the crest of the divide separating the Kiwalik and Buckland drainages. Extensive outpourings of Quaternary basalt have concealed its lower elevations and the figure of 165 square miles given as the area in table 1 is a minimum. The pluton intrudes Lower Cretaceous andesitic volcanic rocks and a K/Ar age of 102 ± 5 m.y. and a Pb-α

age of 90 ± 10 m.y. (Patton, 1967) have been obtained from the pluton. Its southern margin, where not covered by basalt, is mostly fault bounded.

The pluton is composed of medium-grained generally porphyritic monzonite and quartz monzonite; the range of composition is indicated in table 3. The phenocrysts are large pink tabular K-feldspar; quartz, where present, is interstitial. Pyroxene and hornblende are the chief mafic constituents.

The most characteristic feature of the pluton is a persistent cataclastic texture found in specimens throughout the pluton. This texture is locally visible in hand specimen but is particularly noticeable in thin section. The interstitial quartz has been the mineral particularly affected, the end result in some cases being a crushed and fragmented mosaic.

Plutonic rock clasts identical in composition and cataclastic texture to the Hunter Creek pluton have been found in conglomerate 15 miles to the east of the pluton. The age of the conglomerate is uncertain but it is believed (Patton, 1967) to be approximately correlative with volcanic graywacke of late Early Cretaceous (Albian) age to the north and east. The correlation between rocks of the pluton and clasts in the conglomerate serves to set an upper age limit based on field evidence for the pluton. The top of the Albian section is considered to be about 100 m.y. old; even taking into consideration the uncertainties of age determinations, this suggests that the area was tectonically active and that unroofing of the pluton was fairly rapid.

Mid-Cretaceous plutons in the western Purcell Mountains

General character

The three plutons in the western Purcell Mountains (plate 3) are the easternmost plutons of the mid-Cretaceous suite. These are the Shiniliaok Creek, Purcell Mountain, and Hawk River plutons; all three are small bodies, each less than 40 square miles in area. The plutons intrude Lower Cretaceous andesitic volcanic rocks; the Purcell Mountain and Shiniliaok Creek bodies have been dated at 98.6 m.y. and 99.4 m.y. respectively by K/Ar methods (table 2). These two plutons are partially overlain by Upper Cretaceous hypabyssal dacite and rhyodacite dated at 86 m.y. which has been intruded in turn by the Upper Cretaceous Wheeler Creek pluton. The Hawk River pluton is assigned to the suite on the basis of composition.

The plutons vary considerably in lithology. The Shiniliaok Creek pluton consists chiefly of monzonite and syenodiorite as does the Hawk River stock. The Purcell Mountain mass, however, is chiefly quartz monzonite.

If the K/Ar ages of the plutons (~100 m.y.) and the overlying dacitic hypabyssal rocks (86 m.y.) are correct, little time elapsed between plutonism and unroofing of the pluton by erosion. The welded rhyodacite tuff overlying the Purcell Mountain pluton contains clasts of plutonic rock that most likely came from the pluton itself. The plutons therefore appear to be epizonal bodies.

Purcell Mountain pluton

This small body lies just west of Purcell Mountain (plate 3) and, in contrast to the nearby quartz-poor Hawk River and Shiniliaok Creek bodies, is composed chiefly of quartz monzonite (table 3) and granodiorite with a quartz content ranging from 17 to 23 percent. In the narrow arm that projects toward the east, the quartz content drops below 10 percent, possibly due to wall rock contamination. Plagioclase (An_{33-40}) is generally more abundant than the perthitic K-feldspar; hornblende and biotite are the principal mafic minerals but colorless clinopyroxene occurs in the narrow east-trending arm which is probably the contaminated crest of the pluton.

The rocks of the pluton are generally medium grained and commonly porphyritic with tabular K-feldspar phenocrysts up to an inch long. The groundmass texture is hypidiomorphic granular.

Hawk River pluton

A small stock of olivine-bearing monzonite crops out along and near the Hawk River a few miles south of the Purcell Mountain pluton and is cut by an east-west trending fault. This pluton has not been dated but is assigned to the mid-Cretaceous suite on the basis of its monzonitic composition and location.

The pluton is somewhat similar in composition to the Shiniliaok Creek pluton but contains a more calcic plagioclase (labradorite An_{46-48}), accessory olivine, and an unusually colored apatite which is dichroic from light blue to lavender. The olivine was partly reacted to biotite and magnetite. The principal mafic constituents are biotite and clinopyroxene.

The typical rock of the pluton is medium grained and massive with a hypidiomorphic and equigranular texture.

Shiniliaok Creek pluton

This pluton is composed chiefly of medium-grained monzonite and syenodiorite cut by numerous reddish-colored dikes of fine-grained quartz syenite. Small, rounded inclusions of plutonic and andesitic country rock are common throughout the pluton. Quartz is generally present but forms less than 10 percent of the rock except in the quartz syenite (table 3). Plagioclase is usually andesine (An_{34-40}) and somewhat more abundant than the perthitic orthoclase. Biotite and colorless clinopyroxene are the principal mafic minerals; hornblende is less common. In addition to the usual accessories of sphene, magnetite, zircon, and apatite, tourmaline is widespread as an accessory. Tourmaline also occurs as massive lenses in fault zones.

The average mode of 16 representative specimens of monzonote and syenodiorite is 3.9 percent quartz, 47.7 percent plagioclase, 30.6 percent K-feldspar, and 17.7 percent mafic minerals. Chemical analyses were obtained on two specimens of monzonite (table 5). The analyzed specimens resemble the average alkali syenite of Nockolds (1954) more than his average monzonite; the two analyzed specimens have a rather high alkali content

Table 5. Chemical data of the Shiniliaok Creek pluton

	Chemical Analyses (weight percent) 65 AMm181	65APa88		Semiquantitative Spectrographic analyses (parts per million) 65AMm181	65APa88
SiO_2	60.2	61.4	B	20	10
Al_2O_3	17.3	18.1	Ba	2000	2000
Fe_2O_3	2.7	2.3	Be	5	2
FeO	1.8	1.4	Co	10	7
MgO	2.0	1.3	Cr	50	15
CaO	3.7	2.4	Cu	30	15
Na_2O	5.3	5.5	La	150	200
K_2O	4.5	5.3	Nb	30	50
H_2O^-	.20	.08	Ni	20	7
H_2O^+	.73	.52	Pb	100	100
TiO_2	.89	.99	Sc	15	7
P_2O_5	.37	.23	Sn	--	--
MnO	.13	.10	Sr	1500	1000
CO_2	.05	.08	V	150	100
Sum	100.00	100.00	Y	30	50
			Zr	300	300
			Ce	300	500
			Ga	20	20
			Yb	3	5
			Nd	150	200

	Norm (weight percent)	
q	3.6	3.1
or	26.9	31.6
ab	45.3	47.0
an	10.2 18[a]	9.1 16
c	--	--
wo	2.3	0.4
en	5.0	3.3
fs	--	--
mt	3.7	2.0
hm	0.2	1.0
il	1.7	1.9
ap	0.9	0.6
cc	--	0.18
DI	75.8	81.7

Mode (volume percent)		
Quartz	1.5	0.2
Plagioclase	40.6	34.6
K-feldspar	43.2	54.6
Mafic Minerals	13.9	10.6
Met. Opaques	0.8	0.7
Accessories	--	1.3

[a]An content.

(10 percent) and a relatively high SiO_2 content. The latter is reflected in the normative quartz in both specimens. The K_2O/Na_2O ratio is about 1.0.

B. ALKALINE ROCKS

Associated with the granitic rocks of the mid-Cretaceous suite is a belt of alkaline plutonic rocks extending for about 180 miles northeast from the southern Darby Mountains and the Bering Sea (fig. 9). The occurrence of a zoned alkaline complex at Cape Dezhnev on the easternmost tip of Siberia that is very similar to one found in western Alaska (i.e., Granite Mountain) suggests that the belt may extend into Siberia. The similarity in chemistry and lithology, particularly the ultrapotassic character of the alkaline rocks, suggests that all of these occurrences are part of a previously unreported alkaline rock province.

Alkaline plutonic rocks were first reported in western Alaska by Moffit (1905, p. 29) who mentioned finding melanite-garnet bearing rock at Granite Mountain which "corresponds very closely in appearance and composition with the garnet pyroxene malignites which Lawson has described from Maligne River in Ontario." Smith and Eakin (1911, p. 67) reported that nepheline-bearing intrusive rocks were associated with fine-grained granite on Kachauik Creek in the Darby Mountains of the southeastern Seward Peninsula.

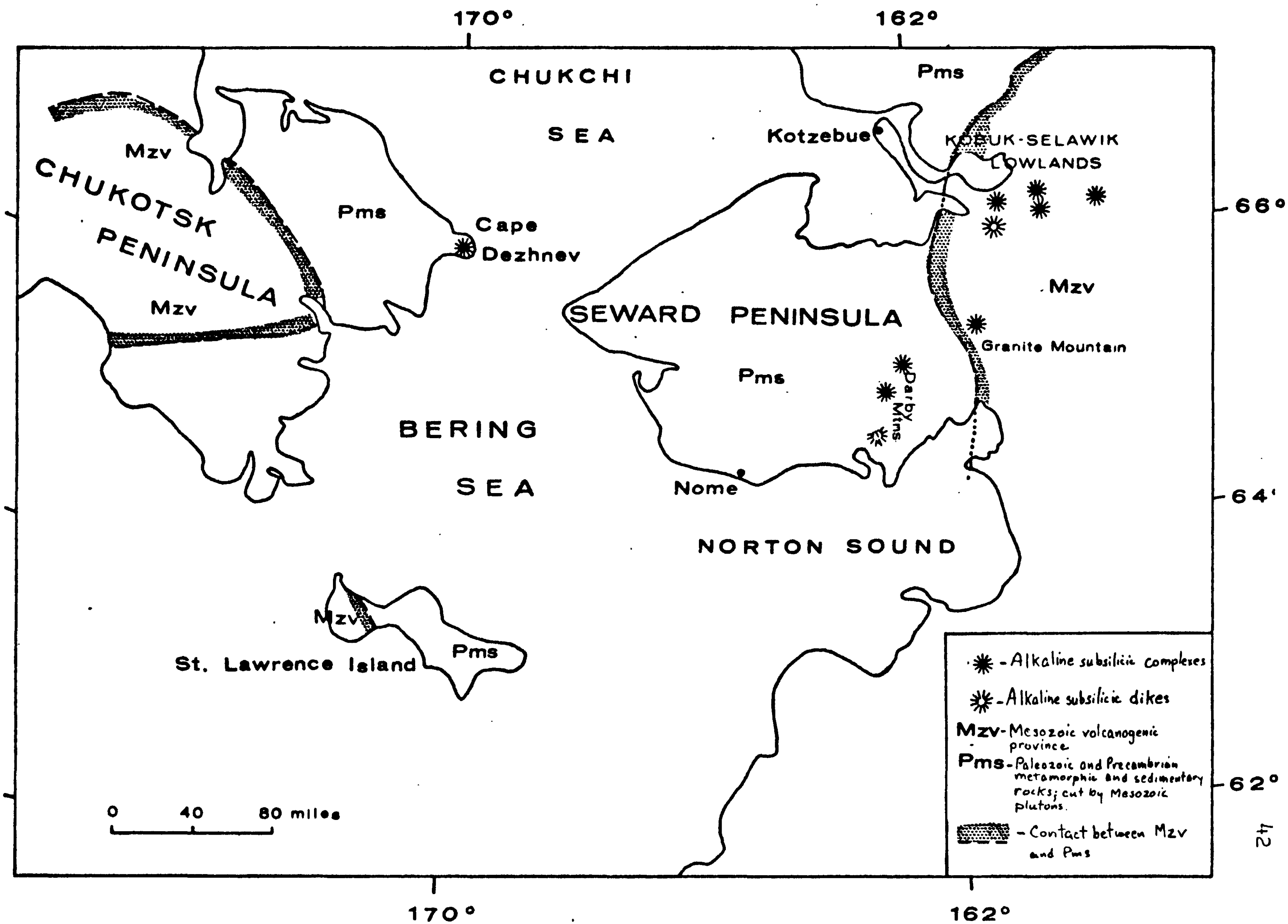


Figure 9. Distribution of known alkaline plutonic rocks in western Alaska and Siberia

Recent geologic mapping (Patton and Miller, 1968; Patton, Miller, and Tailleur, 1968) has shown that alkaline plutonic complexes also occur in the southern Kobuk-Selawik Lowlands at Selawik Lake, Inland Lake, Hunt Creek, and Ekiek Creek (plate 2). The occurrence of nepheline syenite dikes in the nearby Selawik Hills pluton has already been mentioned.

Reconnaissance mapping by the author in the Darby Mountains in 1970 has shown numerous pulaskite and pseudoleucite porphyry dikes cutting monzonite and quartz monzonite that is quite similar to that found in the mid-Cretaceous suite of west-central Alaska. Two other occurrences of alkaline rocks were also found in the northern Darby Mountains. Detailed mapping and petrographic studies have not yet been made on these alkaline rock occurrences in the southeastern Seward Peninsula; however, geologic mapping is now of sufficient detail and extent to indicate that alkaline plutonic rocks are not found elsewhere on the Peninsula.

The complexes in the Kobuk-Selawik Lowlands, at Granite Mountain, and at Cape Dezhnev are discussed below. The other alkaline rock occurrences in the southeast Seward Peninsula will be discussed in a later report.

Alkaline complexes in the Kobuk-Selawik Lowlands

The complexes in the Lowlands underlie rounded and glaciated hills (fig. 10) rising up to 1,400 feet above the Quaternary alluvium. The partial cover of glacial drift together with the

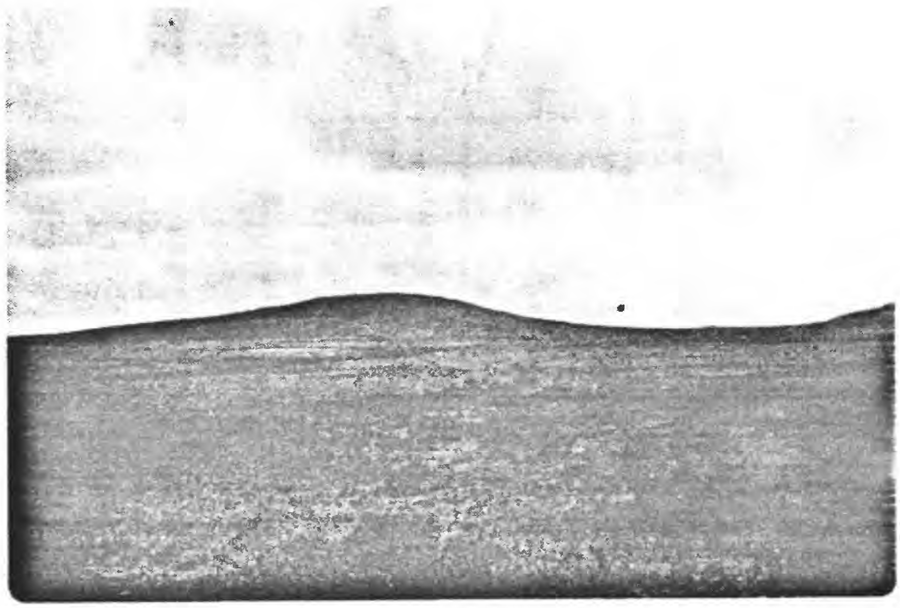


Figure 10. Hunt Creek complex, Kobuk-Selawik Lowlands.

intensive frost action has resulted in scattered exposures of frost-riven rubble. A wide variety of different rock types makes up the complexes, and the poor exposures have prevented detailed mapping. The term complex is a particularly appropriate one to describe these bodies because of the abundance of diverse rock types.

The alkaline bodies are circular to oval in shape and range from 5 to 15 square miles in area. The Hunt Creek and Inland Lake complexes are only 4 miles apart and separated only by alluvium and colluvium--they could be part of the same body.

The alkaline complexes are generally surrounded by alluvium; where country rock is observed, it is usually saturated syenite and, less commonly, quartz monzonite and andesite. The poor exposures prevent a determination of the contact relationships in most places. However, it is clear that the contact is abrupt and no transitional rocks have been found that might indicate metasomatic activity. At the southern contact of the Ekiek Creek complex dikes of melanite-bearing juvite (borolanite) were observed cutting quartz monzonite. Because of the abrupt contacts, lack of transitional rocks showing metasomatic alteration, and the cross-cutting relationships at Ekiek Creek, the alkaline complexes of the Kobuk-Selawik Lowlands are considered to be magmatic rocks.

A K/Ar age of 107 m.y. has been obtained on biotite from a malignite in the Hunt Creek complex (table 2) and these alkaline rocks are considered to be part of the mid-Cretaceous plutonic suite.

Each of the complexes has its own special lithologic characteristics and consists of a variety of rock types (see fig. 3 for classification) which are summarized in table 6; several rock types, however, typify the complexes in the Lowlands although any individual complex may not necessarily contain them all. These rock types are:

(1) Malignite and foyaite--the most abundant rock type and found in all the complexes. Malignite is typically a dark equigranular rock, massive and medium grained (fig. 11), with gray feldspar, pink to orange nepheline (color due to alteration), and black biotite and pyroxene. It is gradational into feldspar-bearing pyroxenite. Foyaite is more felsic and commonly shows a trachytoid texture (fig. 12).

(2) Juvite and borolanite--light-colored equigranular rocks with gray feldspar, fresh green nepheline, and black biotite. Typically medium grained, massive. Locally black garnets (melanite) up to 1/2 inch in diameter are very abundant and rock is called borolanite after Horne and Teall (1892). These rocks are also found in all complexes and also as dikes cutting the Selawik Hills pluton.

(3) Pulaskite and perthosite--blue-gray, fine-grained equigranular rocks commonly forming late dikes. Abundant purple fluorite.

Miscellaneous rock types such as trachyte, ijolite, biotite pyroxenite, and lamprophyre occur in one or more complexes, but are

Table 6. Alkaline rocks of the Kobuk-Selawik Lowlands

Complex	Size (square miles)	Description
Selawik Lake	7	Northern half of complex composed of massive, leucocratic juvite and borolanite forming a high hill 3 square miles in area. Melanite locally very abundant ranging up to 15 percent. Cut by pulaskite and lamprophyre dikes. Southern half very poorly exposed; includes perthosite, malignite. Complex is in contact with saturated syenite.
Hunt Creek	5	Chiefly malignite and foyaite cut by very abundant red trachyte porphyry. Also includes pulaskite dikes, fine-grained borolanite. Complex intrudes andesitic volcanic rocks.
Inland Lake	12 (est.)	Very poorly exposed; northern part pulaskite, southern part malignite and foyaite. In contact with syenite and alaskite.
Ediek Creek	5	Has wide variety of rock types; northern part chiefly malignite and pyroxenite but by foyaite and juvite. Southern part chiefly borolanite with mafic septa(?) of wall rock and minor biotite pyroxenite and ijolite. Borolanite dikes cut quartz monzonite country rock.

Figure 11. Malignite from the Hunt Creek complex.

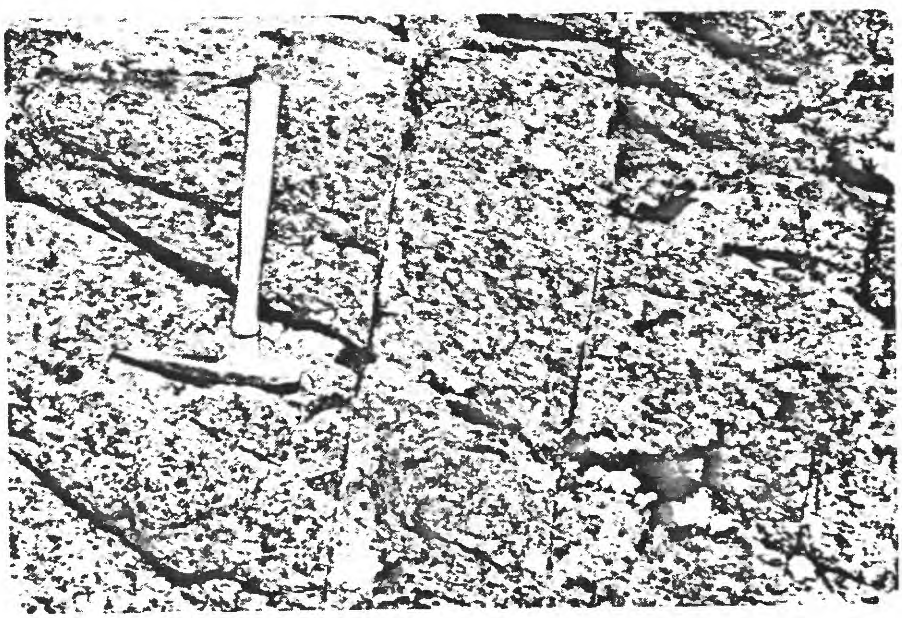


Figure 12. Foyaite from a dike in the Selawik Hills pluton; note trachytoid ("foyaitic") texture.

not abundant with the exception of trachyte porphyry which forms a major part of the Hunt Creek complex. This trachyte porphyry is characterized by large pink sanidine phenocrysts in a reddish-orange groundmass and intrudes the malignite.

The mafic rocks, such as malignite and feldspar-bearing pyroxenite, appear to have been emplaced first and are cut by later, more felsic rocks such as foyaite, juvite, and pulaskite (fig. 13).

Carbonatites have not been found in the province. This may be due to a combination of scarcity and poor exposure; however, Smith (1956) concluded that pyroxenite and ijolite, and not nepheline syenite, are the rocks most commonly associated with carbonatite. Ijolite has been found in only one small locality and true pyroxenites are rare in the western Alaska province.

Petrography

The alkaline rocks of the Kobuk-Selawik Lowlands are single feldspar (hypersolvus) rocks (Tuttle and Bowen, 1958) and their alkaline character is expressed mineralogically by the presence of both alkali feldspar and nepheline. Ultramafic and feldspar-free rocks are rare. Essential minerals are alkali feldspar, nepheline, pyroxene, and biotite; hornblende and melanite garnet are common but show a considerable range in abundance.

The alkali feldspar is generally a fresh clear simply twinned variety commonly with a low 2V. Perthite is found only in late leucocratic pulaskite and perthosite dikes. Plagioclase is found as a separate phase only in the perthite. X-ray studies of

Figure 13. Malignite cut by juvite; Ekiek Creek complex.

several alkali feldspars shows that these are very potassic (up to Or_{96}) and are mostly orthoclase but include some sanidine. The only microcline observed was in small veinlets cutting the Selawik Lake complex; X-ray studies showed this to be a maximum microcline, $\Delta(2\theta_{1\bar{3}0} - 2\theta_{130}) = 0.84^\circ$.

Nepheline is the principal feldspathoid mineral and locally ranges up to 35 percent of the rock. It varies from fresh to highly altered grains--the alteration products being chiefly cancrinite and zeolite. Rarely it is microscopically zoned. X-ray diffraction peaks for $(20\bar{2}2)$ and $(21\bar{3}0)$ were studied for three nepheline samples using an internal CaF_2 standard. The nepheline ranges from Ne_{71} to Ne_{79} according to the curves of Hamilton and MacKenzie (1960). A "finger-print" intergrowth of nepheline in alkali feldspar (fig. 14) is found in all rock types; such intergrowths are not uncommon in alkaline rocks elsewhere and Bowen (1928, p. 257) has suggested such intergrowths are common in pseudoleucite.

Kalsilite, the potassium analog of nepheline, has been identified in borolanite and juvite of the northern part of the Selawik Lake complex. The kalsilite occurs associated with nepheline in complex grains (fig.15) somewhat similar to those described by Sahama (1962). Its presence was originally suspected because of the high K_2O content (16.6 percent) in specimen 11, table 7. X-ray diffraction studies showed that kalsilite was indeed present; it had been included in the nepheline in the modal analyses.

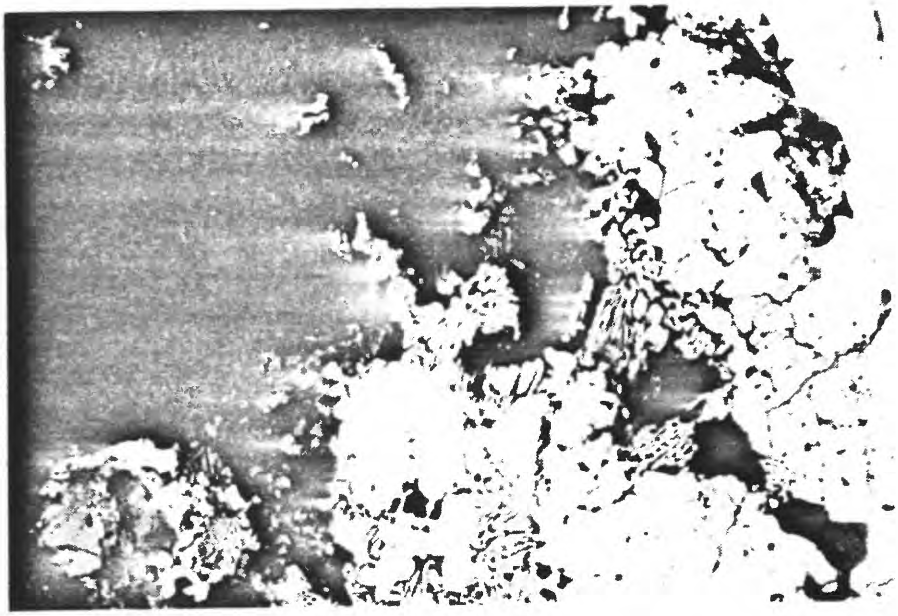


Figure 14. Finger-print intergrowth of nepheline in alkali feldspar. Borolanite from Selawik Lake complex (12X).

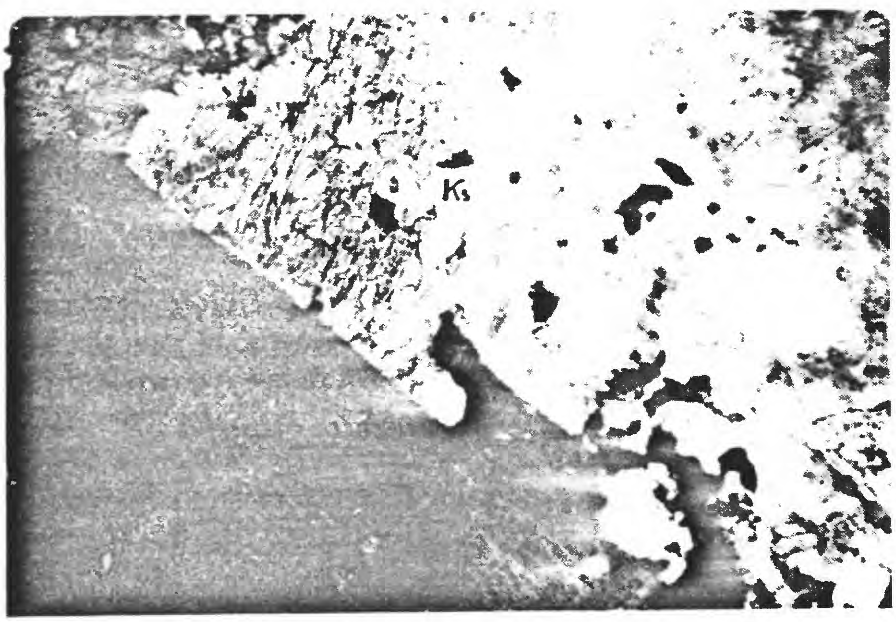


Figure 15. Complex crystal of kalsilite and nepheline from juvite in the Selawik Lake complex (12X).

Kalsilite is not a common mineral and was formerly thought to be restricted to volcanic rocks (Deer and others, 1963; p. 233; Sahama, 1953). Zhidkov (1963), however, found kalsilite in potassium-rich pseudoleucite syenites in the Synnyr massif of the North-Baikalai alkaline region, U.S.S.R. Its occurrence in the Selawik Lake complex would appear in part to be a function of the K_2O/Na_2O ratio.

Clinopyroxene and biotite are the chief mafic minerals; hornblende is common in late leucocratic dikes but occurs only sparingly in more mafic rocks. The pyroxene occurs as subhedral light to dark green grains, commonly zoned with a dark green rim and a light green to colorless core and slightly to moderately pleochroic. Biotite is usually in laths with ragged ends and contains inclusions surrounded by pleochroic haloes. It is intensely pleochroic with X = yellow to gold, Y = dark brown and Z = very dark brown to opaque. A pale green biotite is locally found associated with melanite as an alteration product. The pleochroism, low 2V, and the extinction angle Z∧C of 15° or less suggests it is ferrohastingsite.

Melanite, a black titaniferous variety of andradite, is a major constituent in borolanite but is also common as an accessory in malignite, foyaite, and shonkinite. The melanite occurs as anhedral to euhedral crystals up to 1 cm across and contains inclusions of magnetite, biotite and, more rarely, pyroxene. It is commonly partially rimmed by sphene and titaniferous magnetite. In thin section its color ranges from brown to deep red and zoning, as indicated by a deeper colored core, is common. Semiquantitative spectrographic analyses of two melanite separates showed them to contain 2.0 and 1.5 percent Ti (3.3 and 2.5 percent TiO_2) respectively.

Sphene is the most abundant accessory mineral and commonly appears to be in reaction relationship with melanite. Zircon, apatite, and magnetite are other ubiquitous accessories; fluorite and eudialyte are common in the leucocratic rocks.

Chemistry

Chemical analyses were obtained in 16 specimens which represent the range in composition of the alkaline rocks of the Kobuk-Selawik Lowlands. Some of the chemical characteristics seen in table 7 are:

(1) The SiO_2 content is low and ranges from 45 percent in biotite pyroxenite and ijolite to 58 percent in pulaskite and foyaite.

(2) Alumina ranges from 11 percent in biotite pyroxenite to 22 percent in pulaskite and juvite.

(3) Lime, magnesia, and iron show expected trends from high values in the melanocratic rocks to low values in the leucocratic rocks. CaO ranges from 1.3 percent in pulaskite to 12.2 percent in biotite pyroxenite. MgO is highest (10.3 percent) in a specimen of lamprophyre dike and lowest (0.13 percent) in juvite.

Table 7. Chemical data of the alkaline rocks of the Kobuk-Selawik Lowlands

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Rapid rock chemical analyses (weight percent)																	
SiO_2	44.5	45.1	48.9	49.6	50.3	50.7	51.4	52.2	52.4	54.3	55.4	55.8	57.2	57.8	58.1	58.4	54.8
Al_2O_3	10.9	15.0	12.1	11.6	14.9	17.6	12.2	15.2	19.8	17.1	21.6	15.1	21.3	22.1	22.0	18.2	15.5
Fe_2O_3	4.3	5.1	2.6	1.5	3.4	5.9	6.2	2.8	2.8	2.7	.60	2.3	1.9	.54	1.4	2.1	2.8
FeO	7.7	5.1	5.2	5.4	4.0	1.2	2.7	4.2	1.2	2.4	1.0	3.8	1.0	.60	1.0	2.0	3.2
MgO	9.1	4.4	8.7	10.3	5.4	.17	6.4	4.6	.64	3.2	.13	3.2	.15	.35	.17	.90	2.5
CaO	12.2	11.6	10.5	11.1	8.8	8.0	9.7	7.2	2.5	4.2	.89	6.5	1.4	1.0	1.3	2.8	6.8
Na_2O	1.1	7.0	.91	1.9	2.4	2.0	2.2	2.8	2.3	3.5	1.3	3.2	7.6	4.7	7.9	3.1	4.0
K_2O	4.4	3.4	6.1	5.2	6.3	11.3	5.0	7.3	10.3	7.2	16.6	7.0	8.1	9.4	5.8	9.8	5.8
H_2O-	.29	.27	.49	.18	.24	.19	.30	.19	.84	.68	.12	.26	0.8	.39	.11	.09	.04
H_2O+	1.5	1.0	1.4	1.4	1.6	1.1	1.1	1.2	3.3	3.1	.80	1.0	.66	2.4	1.2	1.0	.8
TiO_2	2.0	.38	1.6	.91	1.2	1.2	1.2	1.2	1.1	.71	.28	.96	.29	.27	.22	.76	1.4
P_2O_5	1.2	.68	.69	.38	.71	.08	.86	.67	.15	.29	.06	.39	.03	.06	.01	.16	.44
MnO	.21	.43	.17	.15	.17	.14	.17	.15	.14	.15	.03	.17	.09	.04	.09	.12	.20
CO_2	.05	.18	.00	.00	.05	.00	.00	.00	.36	.08	.21	.00	.00	.00	<.05	.00	.00
Total S as SO_3	.00	.34	.00	.00	.00	.00	.00	.00	.00	.00	--	.00	.00	.00	--	--	.00
ZrO_2	.05	.03	.04	.04	.10	.20	.04	.04	.05	.09	--	.07	.11	.02	--	--	.06
Cl	.00	.00	.00	.00	.00	.01	.01	.00	.00	.00	--	.00	.01	.00	--	--	.00
F	.34	.11	.33	.30	.25	.40	.20	.18	.12	.15	--	.20	.40	.05	--	--	.57
BaO	.44	.06	.72	.27	.27	.13	.38	.29	1.25	.17	--	.18	.01	.13	--	--	1.12
CIPW Norms (weight percent)																	
or	21.5	14.2	34.9	27.1	37.3	39.5	29.6	43.1	61.8	42.8	42.4	41.4	47.7	55.8	34.6	58.3	34.3
ab	--	--	--	--	7.3	--	18.6	8.1	7.6	22.9	--	20.8	22.5	22.9	38.7	20.0	27.4
an	11.8	.6	10.9	7.8	11.3	5.7	8.7	7.3	10.8	9.7	2.7	6.2	.1	4.5	6.4	6.8	7.2
lc	3.5	4.7	0.9	2.8	--	21.3	--	--	--	--	44.5	--	--	--	--	--	--
ne	5.0	30.9	4.2	8.7	7.1	9.1	--	8.4	6.6	3.8	6.0	3.4	22.5	9.2	15.5	3.5	3.5
wo	16.6	21.3	15.0	18.1	11.1	12.8	14.1	9.9	--	3.4	--	9.5	1.6	--	--	2.5	9.1
en	11.4	11.0	11.0	12.8	8.3	.4	12.5	6.8	--	2.6	--	6.0	.4	--	--	1.7	6.2
fs	3.9	5.3	2.6	3.7	1.8	--	--	2.2	--	.4	--	2.9	--	--	--	.7	1.6
fo	7.9	--	7.5	9.0	3.7	--	2.5	3.2	1.1	3.8	.2	1.4	--	.6	.3	.4	--
fa	3.0	--	1.9	2.9	.9	--	--	1.1	--	.7	.7	.7	--	.2	.4	.2	--
mt	6.2	7.4	3.8	2.2	4.9	.8	5.8	4.1	1.2	3.9	.9	3.3	2.7	.8	2.0	3.1	4.1
hm	--	--	--	--	--	5.3	2.2	--	2.0	--	--	--	.1	--	--	--	--
il	3.8	.7	3.0	1.7	2.3	2.3	2.3	2.3	2.1	1.4	.5	1.8	.5	.5	.4	1.5	2.7
ap	2.8	1.6	1.6	.9	1.7	.2	2.0	1.6	.4	.7	.1	.9	.1	.1	0.0	.4	1.0
cc	.1	.4	--	--	.1	--	--	--	.8	.2	.5	--	--	--	--	--	--
c	--	--	--	--	--	--	--	--	1.0	--	.5	--	--	2.6	.4	--	--
z	.1	0.0	.1	.1	.1	.3	.1	.1	.1	.1	--	.1	.2	0.0	--	--	.1
fr	.5	.1	.6	.5	.4	.8	.3	.2	.2	.3	--	.3	.8	.1	--	--	1.1

Table 7--continued

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Mode (volume percent)																	
nepheline	3.0	47.0	8.3	--	22.0	34.2	0.5	11.4	28.1	--	21.6*	6.8	12.6	33.8	--	5.7	11.6
feldspar	9.8	0.0	27.6	--	36.0	50.0	42.3	39.2	59.0	--	75.2	57.5	75.1	61.4	--	81.0	56.9
pyroxene	50.9	45.9	37.7	--	28.8	0.2	31.4	31.2	0.1	--	X	17.8	7.2	0	--	0.4	26.8
biotite	29.0	1.0	23.9	--	10.4	0.8	11.9	14.8	7.0	--	1.4	4.5	0	0.8	--	0.1	1.8
hornblende	0	0	0	--	0	0	11.8	.4	0	--	0	11.0	X	3.4	--	10.2	0.3
garnet	0	1.3	0	--	0.6	14.0	0	0	4.3	--	0	0	X	0	--	0.1	0
sphene	2.2	0.3	1.8	--	1.4	X	X	1.4	1.4	--	0	1.4	0.6	0.5	--	1.6	2.2
apatite	2.8	2.5	.4	--	0.8	0.6	1.3	.6	0.4	--	X	1.0	X	0.1	--	0.4	0.5
opaques	2.2	2.0	.2	--	X	0.3	0.4	1.0	X	--	0.5	.1	2.2	X	--	0.3	0.1
fluorite											X		1.8		--	0	0
eudialyte											0		0.4		--	0	0
calcite											1.1						
Semiquantitative spectrographic analyses (ppm)																	
Be	5	10	3	5	7	0	5	5	5	10	3	7	7	5	15	5	
Cu	100	50	70	30	70	10	70	50	15	30	10	30	50	10	5	20	
Ni	100	30	100	200	50		70	50	0	50	0	30	0	0	0	10	
Pb	50	20	30	50	70	0	50	70	70	150	20	70	500	70	200	100	
Sr	1500	3000	2000	1500	3000	1000	3000	3000	5000	1500	1000	1500	1000	3000	700	1000	
Th	0	150	0	0	0	0	0	0	0		0	0	0	0	0	0	
Nb	20	20	30	15	30	15	15	30	70	50	7	70	50	0	50	70	
La	200	1000	150	100	200	50	150	200	200	200	30	200	300	50	200	300	
Ce	500	2000	200	200	500	200	300	500	500	300	0	500	300	0	200	500	
Y	50	15	30	30	50	150	50	50	30	50	10	50	30	0	70	70	
Pr	0	100	0	0	0	0	0	0	50	0	0	0	0	0	0	100	
Nd	200	500	100	70	200	200	100	150	150	100	0	150	70	0	70	300	
Sm	0	0	0	0	50	70	0	0	0	0	0	50	0	0	0	0	
Sn	0	0	0	0	0	30	0	5	0	0	0	10	0	0	10	0	
Gd	0	0	0	0	0	0	0	0	--	0	0	0	0	--	0	0	
Dy	0	0	0	0	0	0	0	0	--	0	0	0	0	--	0	0	

* Estimated 50% kalsilite
X - present

1 Feldspar-besring biotite pyroxenite - Hunt Creek complex
2 Ijolite - Ekiek Creek complex
3 Malignite - Hunt Creek complex
4 Lamprophyre - Selawik Lake complex
5 Malignite - Inland Lake complex
6 Borolanite - Selawik Lake complex
7 Shonkinite - Hunt Creek complex
8 Malignite - Hunt Creek complex
9 Borolanite - Ekiek Creek complex
10 Trachyte porphyry - Hunt Creek complex
11 Juvite - Selawik Lake complex
12 Foyaite - Hunt Creek complex
13 Pulaskite - Hunt Creek complex
14 Juvite - Hunt Creek complex
15 Pulaskite - Inland Lake complex
16 Pulaskite-Juvite - Hunt Creek complex
17 Foyaite - dike in Selawik Hills pluton

(4) The total alkali content is high in all rock types as 12 out of 17 analyzed specimens contain more than 10 percent total alkalis, ranging from a low of 5 percent in ultramafic pyroxenite to a high of 18 percent in juvite. K_2O is consistently high and more abundant than Na_2O in all but two specimens--it reaches a high of 16.6 percent in a kalsilite-bearing juvite.

(5) BaO is high as might be expected from the high K_2O content and ranges up to 1.25 percent in a borolanite. In this particular specimen, alkali feldspar and nepheline constitute 87 percent of the rock; if all the BaO is assigned to the feldspar, it would have 2.1 percent BaO which would be a barium feldspar, according to Deer and others (1963, p. 166). Barium-rich sanidine has been reported by Larsen and others in phonolite from the Highwood Mountains, Montana.

(6) Fluorine and zirconium are high (up to 0.57 percent F and 0.20 percent ZrO_2, respectively); chlorine is low, never more than 0.01 percent.

Among the minor elements, Pb, Sr, and the rare earths La and Ce are relatively high; other rare earths (Pr, Nd, Sm) are found in some samples. The Nb content is always less than 100 ppm and low for alkaline rocks. Parker and Fleischer (1968, p. 21) report that the average Nb content of eight prominent nepheline syenite massifs in the Soviet Union ranges from 100 to 900 ppm.

Erickson and Blade (1963, p. 79) found up to 300 ppm Nb in the analyzed rocks at Magnet Cove, Arkansas.

Nepheline appears in the norms of all except one of the analyzed samples and olivine appears in most which shows the subsilicic character of the rocks. The ultrapotassic nature is illustrated by the appearance of leucite in the norms of six specimens.

The alkaline rocks in the Kobuk-Selawik Lowlands are, therefore, highly alkaline, predominantly potassic, relatively rich in BaO, and strongly undersaturated in silica; they are not subaluminous (i.e., peralkaline), however, since the molar ratio of total alkalis to alumina is always less than one.

Most of the chemical characteristics described above, while illustrating the alkaline nature of the rocks, are similar to those found in many other alkaline provinces throughout the world. Where the western Alaska province is unusual, however, is in a high K_2O content and a high K_2O/Na_2O ratio. In figure 16, K_2O is plotted against Na_2O for the entire western Alaska alkaline province and for three published average nepheline syenites. The potassic character of the Alaskan rocks is shown by the plot of all but three specimens on the potassic side of a 1:1 K_2O/Na_2O line. The three average nepheline syenites, however, plot on the sodic side of the 1:1 K_2O/Na_2O line.

Variation diagrams of Na_2O and K_2O versus the Thornton-Tuttle differentiation index are shown in figure 17. Plots of the

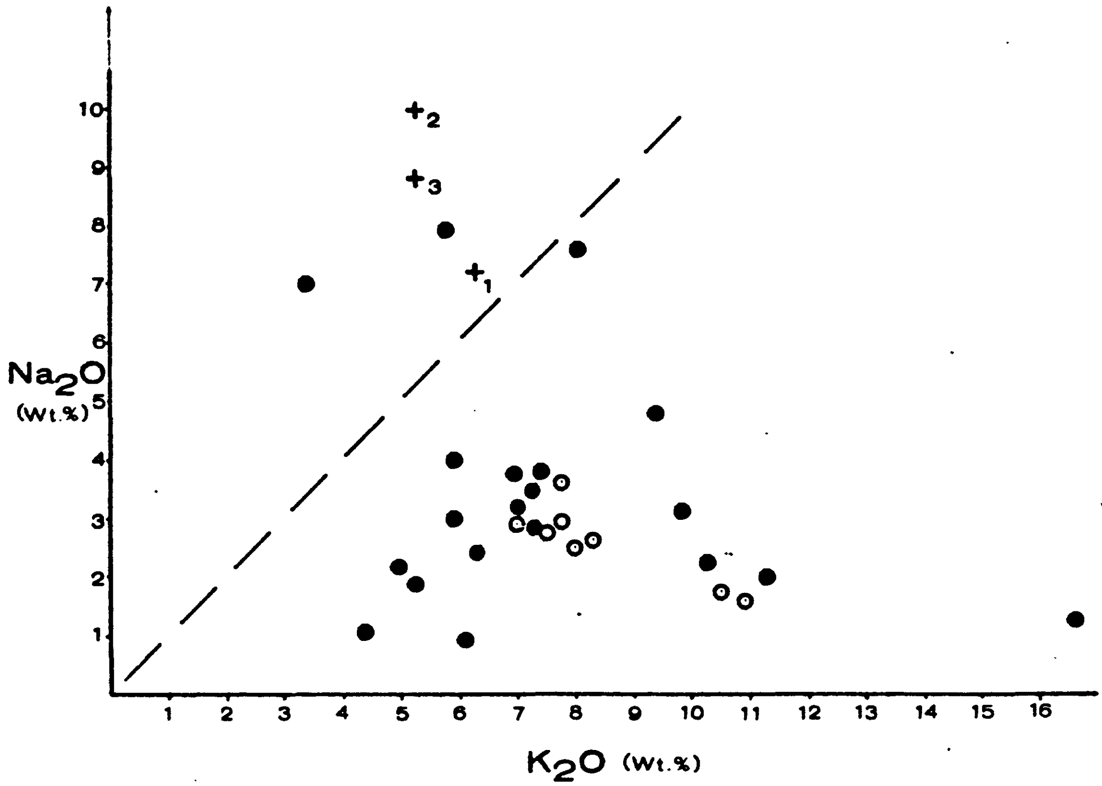


Figure 16. Plot of weight percent K_2O vs. Na_2O from western Alaska alkaline rocks (•), Cape Dezhnev, USSR, (o), and three published average nepheline syenites (+); Nos. 1 and 2 are the average miaskitic nepheline syenite (156 analyses) and average agpaitic nepheline syenite (129 analyses) of Gerasimovskii (1966); no. 3 is the average nepheline syenite (80 analyses) of Nockolds (1954).

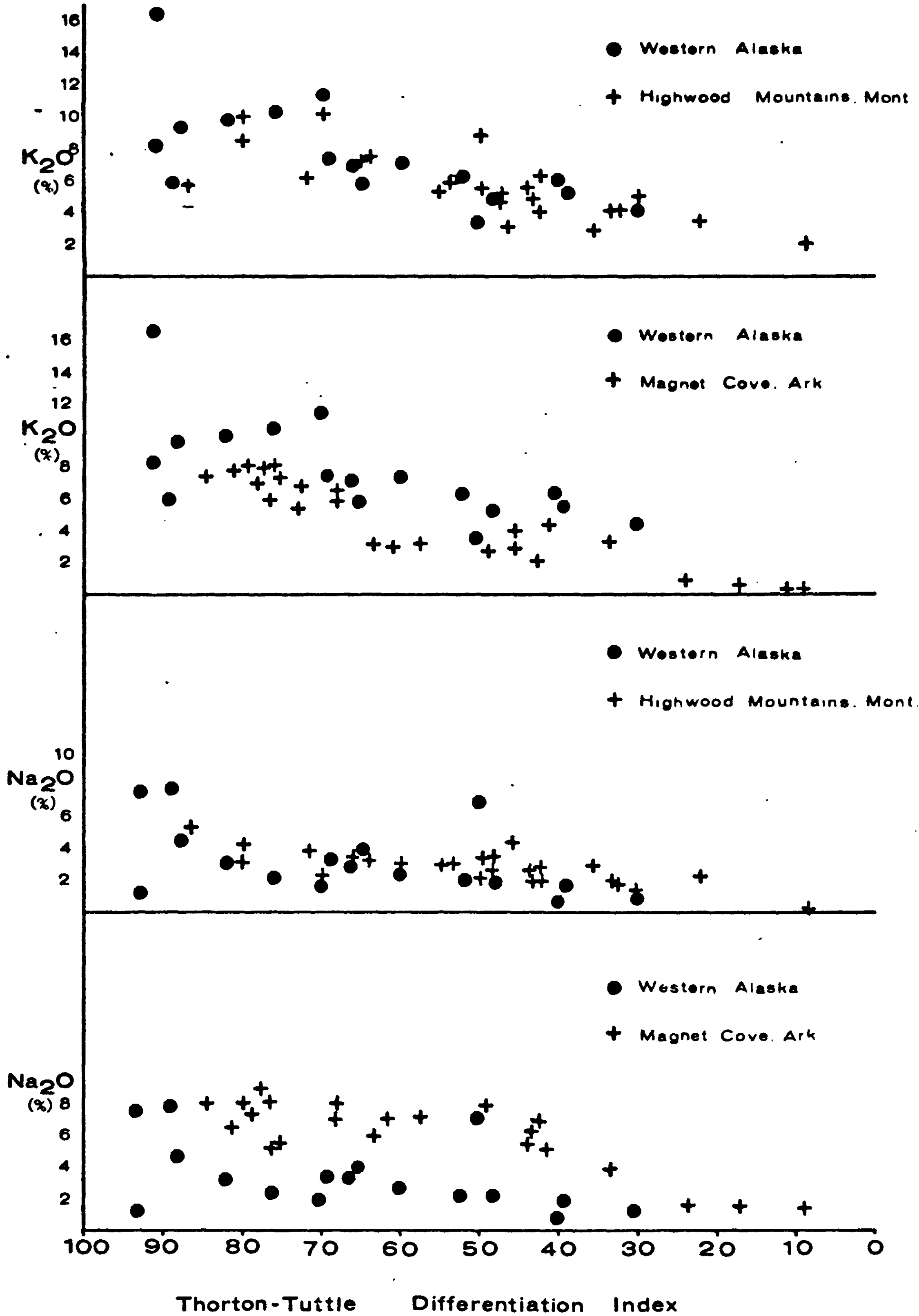


Figure 17. Variation diagrams showing alkalis plotted against Thorton-Tuttle differentiation index for western Alaska, Highwood Mountains, Mont., and Magnet Cove, Ark., alkaline rocks.

Alaska rocks are compared with those from Magnet Cove, Arkansas, a classic alkaline rock occurrence (Erickson and Blade, 1963) and with the classic potassic province of the Highland Mountains of Montana (Larsen, 1941; Buie, 1941; Burgess, 1941). The differences between the Alaskan rocks and those from Magnet Cove stand out clearly; the Alaskan suite has higher K_2O and lower Na_2O. The Magnet Cove rocks are not sodic; they are miaskitic ($Na_2O + K_2O/Al_2O_3 < 1$) in nature and such suites are relatively rich in K_2O. The Highwood Mountain province, however, compares very closely with the Alaskan rocks in both K_2O and Na_2O content. The alkaline rocks of the western Alaska alkaline province are obviously potassium-rich as has been illustrated above.

Granite Mountain pluton

General character

Granite Mountain is underlain by a zoned, roughly circular pluton about 27 square miles in area and forms a prominent high landmark at the south end of the range of hills separating the Kiwalik and Buckland Rivers (plate 1). The pluton is composed of the following four units (plate 4) which were mapped chiefly on the presence of megascopic quartz vs. either nepheline or garnet: (1) a core of equigranular quartz monzonite, (2) an inner crescent-shaped zone of massive to porphyritic monzonite partly surrounding the quartz monzonite, and (3) an outer crescent-shaped zone subdivided into nepheline syenite (foyaite) and garnet syenite.

Contacts between the quartz monzonite and monzonite and between the monzonite and garnet syenite appear to be gradational. Contacts with the nepheline syenite are concealed by tundra and talus cover. Areas of the four mapped units are given below:

Unit	Square miles	Percent of pluton	
Quartz monzonite	8.0	29.3	
Monzonite	12.6	46.2	
Garnet syenite	4.1	15.0	24.5
Nepheline syenite	2.6	9.5	
	27.3	100.0	

Small, poorly exposed satellitic bodies of nepheline syenite are found at low elevations southwest and northeast of the pluton suggesting the nepheline syenite may underlie a larger area at no great depth.

The country rock is Lower Cretaceous (Neocomian) andesitic volcanic rock and the contacts are sharp and appear to dip steeply except near Cub Creek (plate 4) where the contact dips about 50° outward to the north. The pluton is surrounded by a contact aureole of hornblende and albite-epidote hornfels facies rocks extending outward for about a half mile. There appears to have been little metasomatism adjacent to the pluton.

Andesite inclusions are thinly scattered throughout the pluton. Locally they show an orientation but the lack of rock actually in place due to the severe frost action precludes measuring attitudes. A screen of hornfelsic andesite about 300 yards long by 150 yards wide occurs in the northwestern part of the quartz monzonite.

Molybdenite occurs as disseminated grains in syenite in the satellitic stock at Cub Creek and in quartz veins cutting the syenite in that area. Associated with the molybdenum are anomalously large amounts of silver, uranium, bismuth, and lead (Miller and Elliott, 1969).

A K/Ar age of 106±3 m.y. was obtained on hornblende from the inner zone of monzonite (table 2); a Pb-α age of 100±10 m.y. was obtained on zircon from this same unit (Patton, 1967).

Petrography

A plot of the salic modal constituents of all units except the nepheline syenite is shown in fig. 18. This plot shows the relatively uniform character of the quartz monzonite and the relatively heterogeneous character of the monzonite and garnet syenite. A petrographic summary of the mapped units is given in table 8.

Quartz monzonite.--The east-central part of the pluton is composed of fine-grained, hypidiomorphic and equigranular quartz monzonite which is very uniform in composition and texture. Plagioclase occurs as subhedral to euhedral grains with some oscillatory zoning and an average composition of about An_{25-30} or calcic oligoclase. K-feldspar typically occurs as subhedral grains of perthetic orthoclase and microcline and shows some zoning marked both by extinction positions and by zonal arrangement of included

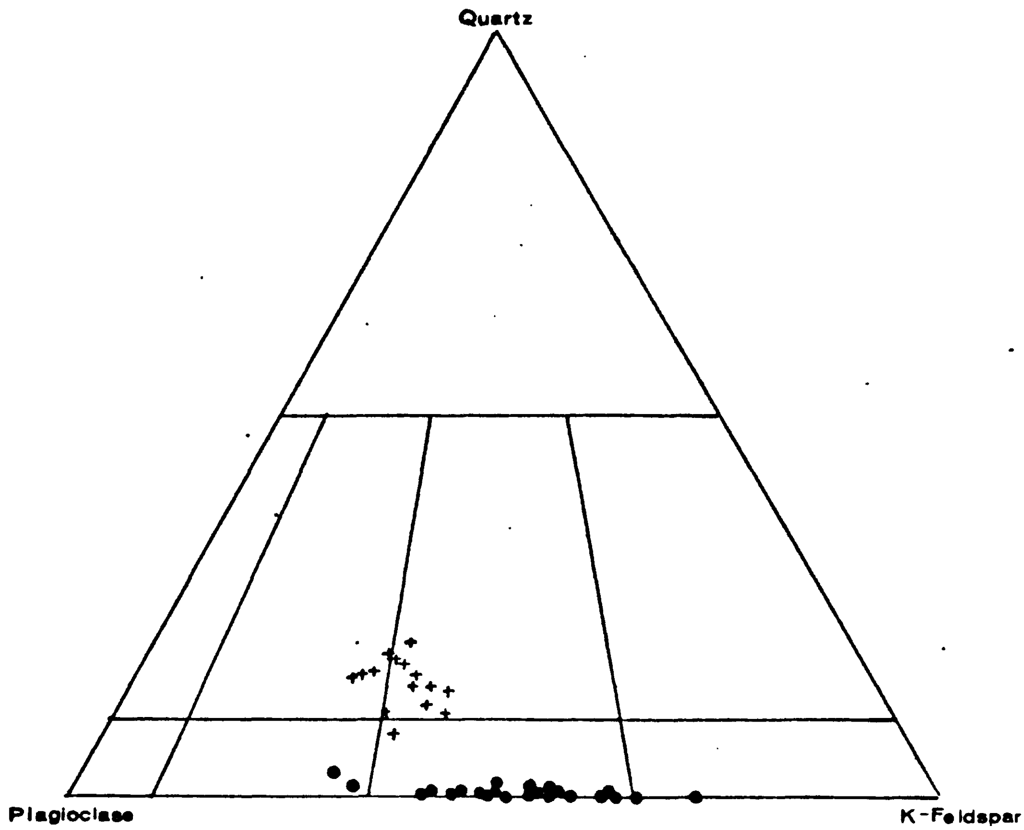


Figure 18. Modal trends of the granitic rocks of the Granite Mountain pluton (+, quartz monzonite; •, monzonite).

Table 8. Petrographic summary of the Granite Mountain pluton

	Quartz monzonite	Monzonite	Garnet syenite	Nepheline syenite (Foyaite)
Quartz	avg. 15 percent	accessory	absent	absent
Nepheline	absent	absent	accessory	range 1-5 percent
K-feldspar	avg. 29 percent	range 28-60 percent	range 31-60 percent	range 60-70 percent
Plagioclase	avg. 51 percent An_{25-30}	range 22-63 percent An_{18-24}	range 22-38 percent An_{28-30}	range 0-15 percent An_{30}
Mafic minerals	avg. 4 percent chiefly hornblende, minor biotite; accessory pyroxene near monzonite	range 6-25 percent chiefly hornblende and pyroxene; garnet near garnet syenite	range 15-30 percent garnet, hornblende, pyroxene	range 10-20 percent garnet and hornblende
Accessories	magnetite, zirzon, allanite	magnetite	fluorite, magnetite	fluorite
	sphene and apatite are ubiquitous			
Fabric	hypidiomorphic and equigranular	outer part porphyritic; inner part equigranular	porphyritic to gneissic	slightly porphyritic
Grain size	fine-grained	medium- to coarse-grained	medium-grained	medium-grained

plagioclase crystals. Quartz is consistently anhedral and interstitial. The most common mafic mineral is hornblende but biotite is present locally and clinopyroxene is an accessory near the monzonite contact.

Monzonite.--The inner crescent zone of monzonite has a range in composition and texture. The outer part of the unit is composed of coarsely porphyritic and even trachytoid rock with a mafic mineral content of up to 25 percent. The inner part consists of a massive, homogeneous rock with a lower mafic index and resembles the quartz monzonite.

Plagioclase occurs as subhedral to euhedral grains of oligoclase (An_{18-24}) and K-feldspar forms subhedral to euhedral grains of perthite commonly with grid twinning. Hornblende and clinopyroxene, the latter commonly zoned with a darker core, are about equally abundant although locally, clinopyroxene is present to the exclusion of hornblende.

The contact with the quartz monzonite is sharply gradational over a distance of a few hundred feet. The contact with the nepheline syenite is not exposed but appears to be fairly abrupt. Aplite and perthosite dikes cut the monzonite.

Garnet syenite.--This unit forms the west and northwest border of the pluton and was mapped according to the presence of megascopic garnet. The garnet crystals are generally conspicuous in hand specimen where they occur as poorly developed dodecahedra with a characteristic resinous brown to black color; locally they constitute up to 20 percent of the rock. The syenite is a medium to coarse-grained rock with a characteristic porphyritic to gneissic texture. It is the most mafic of the units with the total mafic content locally as high as 30 percent.

The K-feldspar occurs as anhedral to euhedral grains and phenocrysts of perthite. Plagioclase is subhedral calcic oligoclase and sodic andesine (An_{28-30}). Hornblende is euhedral and generally the most abundant mafic mineral. Garnet is typically anhedral and riddled with inclusions of pyroxene, feldspar, and hornblende and locally appears to be intergrown with clinopyroxene. It ranges from almost colorless to dark reddish brown in thin section and is commonly zoned with a darker core. Nepheline occurs as an accessory in some sections, particularly near the andesite contact; it is typically altered to cancrinite and scapolite.

The contact with the monzonite is sharply gradational over a distance again of only a few hundred feet. Dikes composed of fine-grained nepheline syenite locally cut the unit.

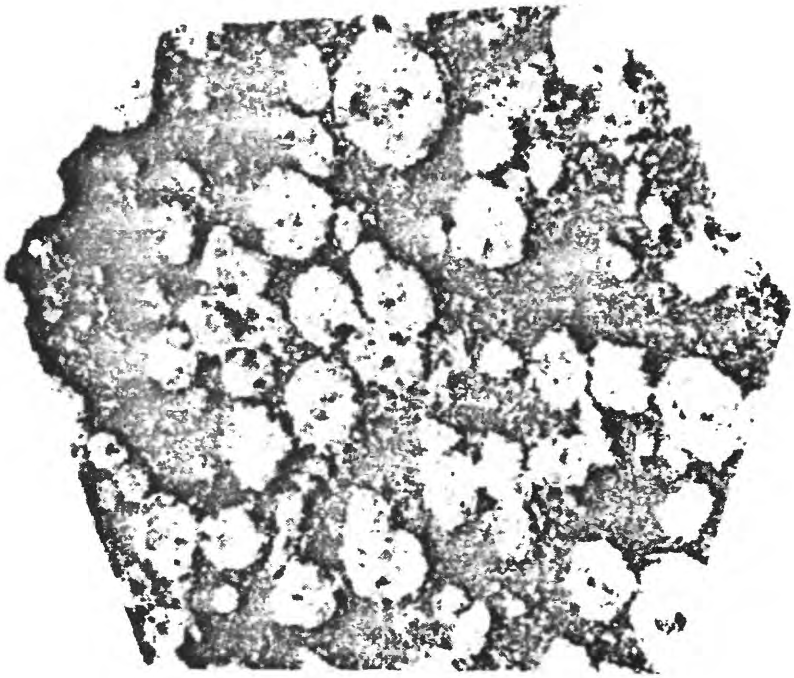
Nepheline syenite and associated rocks.--Alkaline subsilicic rocks are confined chiefly to the southwest part of the pluton where they underlie a low ridge near the airstrip (plate 4). Exposures are poor and even rubble "patches" are not common except near the airstrip where much of the tundra has been removed and large angular blocks of frost-riven rubble are exposed in this area and in a nearby gravel pit.

Foyaite is the principal rock type and is typically a leucocratic medium-grained, massive to slightly porphyritic rock. It is cut by numerous dikes of borolanite and, less commonly, pulaskite and dark green-gray phonolite. A notable feature of the alkaline rocks here is the occurrence of pseudoleucite porphyry as xenoliths in the foyaite. In these rocks, euhedral pseudoleucite phenocrysts up to 2 inches across occur in a groundmass of alkali feldspar, nepheline, garnet, pyroxene and hornblende (fig. 19). Pseudoleucite porphyry also occurs as dikes cutting the andesite country rock; rubble composed of biotite pyroxenite is commonly found associated with these dikes. Float of pseudoleucite porphyry and biotite pyroxenite are found in stream gravels in Sweepstakes Creek and in Cub Creek and in many of their tributaries.

The foyaite is composed essentially of perthite, plagioclase (An_{30}), nepheline, hornblende, and melanite. In contrast to the alkaline rocks of the Kobuk-Selawik Lowlands, the foyaite is not a hypersolvus rock. Another characteristic feature of the alkaline rocks at Granite Mountain is the abundance of melanite.

Chemistry

Ten specimens representing the different zones were selected for chemical analyses and the results are presented in table 9 along with the accompanying semiquantitative spectrographic analyses, norms, and modes. The analyses of rocks from the outer zone of the pluton (garnet syenite, foyaite, and pseudoleucite porphyry)



50 MM

Figure 19. Pseudoleucite porphyry from the Granite Mountain pluton.

Table 9. Chemical data of the Granite Mountain pluton

	Core		Inner rim			Outer rim				
	Quartz monzonite		Monzonite			Nepheline syenite (Foyaite)		Pseudoleucite porphyry	Garnet syenite	
	69AMm34	69AMm30B2	69AMm15	69AMm18	69AMm10	69AMm29	68AMm500	69AMm59	69AMm5A	69AMm9A
SiO_2	65.8	68.2	61.5	59.5	60.4	55.5	55.5	50.0	53.7	55.4
Al_2O_3	17.8	17.1	19.6	18.2	18.1	19.4	19.3	17.4	17.8	19.0
Fe_2O_3	1.6	.80	.46	2.4	1.9	2.8	2.1	4.1	4.8	4.1
FeO	1.0	1.0	1.4	2.4	2.2	2.2	2.6	3.8	3.2	2.2
MgO	.74	.52	.85	1.8	1.4	1.2	1.5	2.8	2.7	1.4
CaO	2.9	2.4	4.3	5.2	4.1	5.1	5.6	9.6	7.3	4.7
Na_2O	4.7	4.8	5.5	5.1	5.1	3.8	3.7	3.0	4.0	4.1
K_2O	4.3	4.0	4.4	3.7	5.3	7.4	6.9	5.9	4.2	6.4
H_2O+	.43	.50	.38	.47	.55	1.5	1.5	1.4	.75	1.5
H_2O-	.13	.11	.10	.10	.67	.21	.20	.19	.20	.20
TiO_2	.36	.25	.45	.65	.59	.62	.65	.90	.73	.59
P_2O_5	.12	.10	.16	.26	.21	.21	.26	.54	.40	.21
MnO	.06	.05	.08	.10	.08	.13	.14	.18	.15	.14
CO_2	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05
Sum	100	100	99	100	100	100	100	100	100	100
				CIPW Norms (weight percent)						
q	15.0	19.0	2.9	3.7	1.2	---	---	---	---	---
or	25.5	23.7	26.2	21.9	31.3	43.8	40.9	35.0	24.9	37.9
ab	39.8	40.7	47.0	43.3	43.2	20.6	22.2	7.0	32.4	29.0
an	13.6	11.3	15.9	15.9	10.9	14.0	15.7	16.7	18.3	14.6
c	0.4	0.7	---	---	---	---	---	---	---	---
ne	---	---	---	---	---	6.3	5.0	10.0	0.9	3.2
wo	---	---	1.9	3.5	3.4	4.1	4.4	11.5	6.4	3.1
en	1.8	1.3	2.1	4.5	3.5	2.9	2.6	7.0	5.0	2.7
fs	.03	.9	1.6	1.5	1.6	.9	1.5	2.4	.7	---
fo	---	---	---	---	---	.08	.8	---	1.2	0.6
fa	---	---	---	---	---	.03	.5	---	.2	---
mt	2.3	1.2	.7	3.5	2.8	4.1	3.1	6.0	7.0	5.9
il	.7	.5	.9	1.2	1.1	1.2	1.2	1.7	1.4	1.1
ap	.3	.2	.4	.6	.5	.5	.6	1.3	1.0	.5
salic	94.4	95.5	92.1	84.7	86.6	84.7	83.8	68.7	76.4	84.6
femic	5.2	4.0	7.6	14.8	12.9	13.8	14.7	29.9	22.9	13.9
DI	80.3	83.4	76.1	68.9	75.7	70.7	68.1	52.0	58.2	70.1

Table 9--continued

Semiquantitative spectrographic analysis (ppm)

	1	2	3	4	5	6	7	8	9	10
B	N	N	N	N	N	15	15	10	15	7
Ba	3000	3000	3000	5000	2000	3000	3000	5000	3000	3000
Be	3	3	5	3	7	5	5	5	5	2
Co	5	2	7	10	10	10	10	20	20	10
Cr	10	5	10	70	50	20	30	70	100	20
Cu	1	L(1)	3	2	2	30	100	100	30	30
La	100	50	100	150	150	150	200	200	150	150
Mo	N	N	N	N	N	3	3	3	3	N
Nb	10	10	10	15	15	15	15	10	15	15
Ni	5	N	5	20	15	10	15	30	50	15
Pb	50	50	70	50	70	100	70	70	100	700
Sc	3	2	3	10	7	5	7	15	15	7
Sr	2000	1500	2000	2000	2000	3000	3000	3000	3000	3000
V	30	20	50	100	70	100	100	200	150	100
Y	15	10	30	50	30	30	30	50	30	50
Zr	150	150	70	200	300	200	200	300	200	200
Ce	150	100	200	200	200	300	300	300	200	300
Ga	20	20	20	20	30	30	20	30	30	30
Yb	1.5	1	1.5	3	3	3	2	3	2	3
Nd	N	N	100	150	150	150	150	200	150	150

Modes (volume percent)

	1	2	3	4	5	6	7	8	9	10
Quartz	13.5	15.4	---	1.6	---	---	---	---	---	---
Plagioclase	46.4	56.7	53.5	57.9	37.7	15.4	9.9	---	37.9	21.9
K-feldspar	34.3	24.8	38.7	28.8	48.9	60.6	73.5	---	30.9	59.7
Biotite	---	0.3	---	---	---	.2	---	---	.5	.7
Hornblende	5.5	2.8	.9	7.2	5.9	13.2	7.2	---	21.7	11.5
Pyroxene	0.2	---	6.0	3.8	6.9	X	.6	---	5.6	1.0
Nepheline	---	---	---	---	---	4.8	4.7	---	---	---
Melanite	---	---	---	---	---	3.4	3.6	---	3.4	5.2
Met. Opaques	---	---	.9	.6	.6	---	---	---		

show chemical characteristics similar to the alkaline rocks of the Kobuk-Selawik Lowlands. The total alkali content is high and K_2O is again greater than Na_2O. In the monzonite and quartz monzonite of the interior part of the pluton, however, Na_2O increases slightly and is greater than K_2O in four out of five analyzed samples. Alumina is high in all specimens ranging from 17.1 to 19.6 percent. CaO, MgO, FeO, and Fe_2O_3 all decrease as silica increases from the alkaline rocks of the outer zone to the more silicic core. Similar decreases can be seen in the trace elements Co, Cr, Cu, Ni, Sc, and V; B and Mo occur only in the alkaline rocks of the outer zone.

Cape Dezhnev massif, USSR

A zoned alkaline massif very similar to that at Granite Mountain has been mapped by Perchuk (1965) at Cape Dezhnev on the easternmost tip of Siberia (fig. 9). Because of this similarity and because the Cape Dezhnev body may represent the continuation of the western Alaska alkaline province into Siberia, a summary of Perchuk's work is included here.

The pluton has a granite core and grades through quartz syenite to syenite (garnet-bearing) and finally nepheline syenite (foyaite) in the outer rim. The following mineralogical characteristics were reported: (1) plagioclase becomes more calcic from core (An_{7-20}) to nepheline syenite rim (An_{30-96}), (2) pyroxene becomes abundant in the quartz syenite, (3) garnet (andradite-melanite) is common in the syenites, and (4) mesocratic varieties of syenite are the most common.

Chemically the suite shows a range from silica-oversaturated to silica-undersaturated rock and is strongly alkaline, potash-rich and peraluminous.

A change in texture occurs that is similar to that at Granite Mountain. The granite has a "weakly" porphyritic texture and the outer zones a more pronounced porphyritic, locally trachytoid, texture. Contacts between all zones are gradational.

The massif is intrusive into Viséan (Lower Carboniferous) limestone and Perchuk quotes a K/Ar date of 55 m.y. for the massif. However, this date may have come from the work of Lugov (1958) who reported two ages of 55 m.y. and one of 80 m.y. for the massif. Unfortunately, Lugov does not state what minerals were dated, gives no supporting analytical data, and does not offer an explanation for the age discrepancies. For these reasons, the absolute age of the pluton must be regarded as uncertain.

Perchuk interprets the zoning and occurrence of alkaline rocks in the rim to "magmatic replacement of limestone" by a granitic magma, in short, the classic limestone syntexis theory of Daly and Shand. I disagree with this interpretation for the following reasons: (1) the volume of alkaline rock (13 square miles of nepheline syenite, 30 percent of the massif) seems too large to be explained by assimilation of limestone in view of the experimental work of Watkinson and Wyllie (1969). They conclude from a study of the composition join $NaAlSi_3O_8$- $CaCO_3$-$Ca(OH)_2$-H_2O that while the development of small amounts of subsilicic alkaline rock may be expected at granitic magma-limestone contacts, large volumes of such rock are unlikely. Limestone assimilation releases CO_2 which tends to induce crystallization of a hydrated magma forcing the magma to crystallize as assimilation proceeds. The occurrence at Granite Mountain of similar zonation where there is no contact limestone also weighs against Perchuk's interpretation. Further evidence against such an interpretation is the high K_2O content of the Cape Dezhnev rocks (up to 10.88 percent) and the high K_2O/Na_2O ratio which is greater than one in all analyzed specimens. This, of course, is very similar to the alkaline rocks on the Alaskan mainland. This striking chemical characteristic of a group of intrusive bodies which are scattered over a narrow belt several hundred miles long would be very difficult to explain if a purely local process such as assimilation were the active mechanism.

Origin of zoning

The type of zoning seen at Granite Mountain and at Cape Dezhnev is relatively rare but has been reported at Loch Borolan in Scotland (Shand, 1939) and at Red Hill in New Hampshire (Quinn, 1937). Among the various mechanisms proposed for the origin of zoning from alkaline silica-undersaturated rocks to silica-oversaturated rocks are: (1) contamination of a granitic magma by limestone assimilation as outlined by Perchuk (1965), (2) separate intrusions of magma differentiated elsewhere (Quinn), and (3) the early separation of leucite as a controlling factor in the differentiation of syenitic magma (Bowen, 1928, p. 255).

Perchuk's hypothesis has already been commented on and thought to be an unlikely mechanism for the production of the zoning at Granite Mountain or at Cape Dezhnev. The gradational contacts between the plutonic units together with the major and minor chemical trends in the Granite Mountain pluton suggest that the various zones do not represent separate intrusive units as suggested by Quinn for the Red Hill complex.

The explanation for the zoning at the Loch Borolan Laccolith given by Bowen and discussed more recently by Fudali (1963) seems to be more compatible with field and petrographic evidence at Granite Mountain. Considering the system $NaAlSiO_4$-$KAlSiO_4$-SiO_2 (petrogeny's residua system, fig. 20), Fudali's discussion goes as follows (p. 1116):

> Consider a magma of original composition b which is quietly differentiating at depth such that leucite is removed from one part of the magma and accumulates in another part (the actual method of removal is unimportant). As the leucite is removed from part of the magma, the remaining liquid follows an approximate fractionation curve to c. At c, leucite is no longer removed and equilibrium conditions become dominant. There are now two magmas in the chamber--c and d. If the two liquids follow approximate equilibrium curves, the final assemblage for c will be feldspar and quartz, and the final assemblage for d will be nepheline, feldspar, and leucite. This is the simplest case. More generally, several zones with gradational contacts might develop by a similar process.

The compositions of the Granite Mountain suite have been plotted in terms of petrogeny's residua system (Q-Ks-Ne) at a pressure of 1,000 bars in the presence of an aqueous vapor phase in figure 20 and a comparison of the compositional trends with the fractionation curves shows a rather close relationship. The

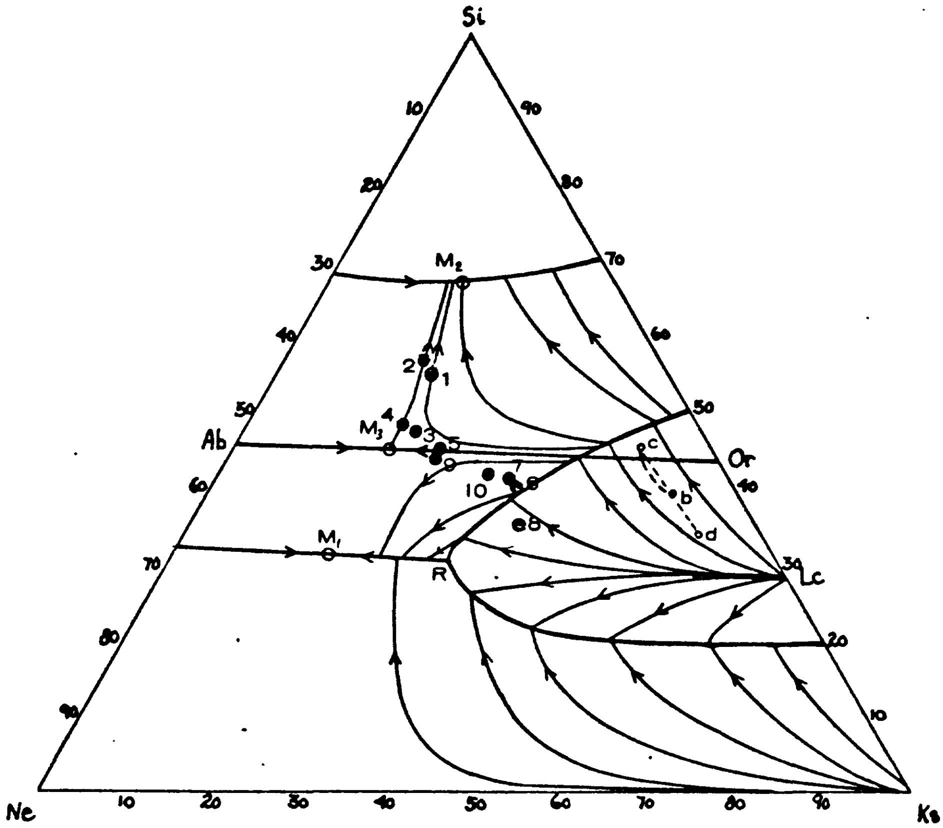


Figure 20. Analyses of the Granite Mountain pluton plotted on a diagram of the system nepheline-kalsilite-silica at a pressure of 1000 bars in the presence of an aqueous vapor phase (after Fudali, 1963, p. 1116). Arrows show fractional crystallization paths; numbers refer to analyses in table 9. $M_{1,2,3}$ are minimums and R is a reaction point.

occurrence of the large pseudoleucite phenocrysts in what appears to be the oldest rock type in the pluton certainly suggests the leucite was separated early similar to the experimental model, the pseudoleucite having formed by the subsolidus breakdown of leucite according to Fudali. Luth (1967) has shown that for bulk compositions initially precipitating leucite or potash feldspar in the system $KAlSiO_4$-Mg_2SiO_4-H_2O, the join enstatite-potash feldspar vapor at P = 2700 bars and in the presence of an aqueous vapor phase remains a thermal barrier as proposed by Yoder and Tilley (1962). Liquids cannot pass over this divide upon fractional crystallization. However, this thermal barrier may not be encountered in water-undersaturated systems. Thus the gradation at Granite Mountain from silica-undersaturated to oversaturated rocks might be compatible with the experimental work of Luth if (1) the pressure were less than 2.7 kb, or (2) if the magma were water-undersaturated.

The plotting of salic normative components of rocks as mafic as some of the analyzed alkaline rocks (DI's as low as 52; table 9) can lead to serious errors. Also, the composition of the pseudoleucite porphyry (no. 8, fig. 20) is probably not the composition of the original magma since it contains the large pseudoleucite phenocrysts. A better estimate of the original composition could be obtained by subtracting the composition of the pseudoleucite phenocrysts from the composition of the rock as a whole. This is currently being done and will be reported on at a later date. In spite of these qualifications, the correspondence between theoretical fractionation curves and the compositional trend of the rocks is striking.

As has been mentioned, Bowen originally proposed this process to explain the zoning at the Loch Borolan Laccolith in northwestern Scotland. The composition of the laccolith ranges from quartz syenite (nordmarkite) through syenite to nepheline syenite at the base. Many of the analyzed nepheline syenites, particularly the borolanites, from this body show K_2O/Na_2O ratios greater than one (Tilley, 1958a) and plot in the primary leucite field. These characteristics are also found at the Cape Dezhnev massif which is even more potassic than Granite Mountain and at the Red Hill intrusive in New Hampshire. Alkaline complexes showing the type of zoning discussed here are rare occurrences. Therefore, the fact that four widely scattered alkaline complexes with the same zonation all show a K_2O/Na_2O ratio greater than one suggests that a requirement for the formation of complexes zoned from alkaline rim to silicic core is that the original magma be potassic.

Differentiation in the Granite Mountain pluton appears to have proceeded from the alkaline to the silicic rocks. However, this differentiation was apparently not <u>in situ</u> since both quartz monzonite and monzonite are in contact with the country rock. A possible explanation is a late pulsation of magma at a stage when the inner part of the pluton was still fluid. The rather abrupt change from a porphyritic to massive texture in the outer zone of monzonite supports such an interpretation.

Regional distribution

The distribution and setting of the alkaline plutonic rocks in western Alaska is shown in figure 9. It is apparent that the alkaline rocks occur in two quite different geologic terrains: (a) the Seward Peninsula platform-like province of thrust-faulted metamorphic and sedimentary rocks of Paleozoic and Precambrian age cut by Mesozoic plutons, and (b) the Yukon-Koyukuk volcanogenic province of Mesozoic age. Formerly, it was thought that alkaline rocks were confined to stable continental shield and platform areas (Backlund, 1932; Tilley, 1958b; Bailey, 1964). However, Zhabin (1959) pointed out the occurrence of an alkaline complex in the Ural geosyncline and stated that the formation of the intrusive is clearly associated with the folding and geosynclinal magmatism. Zhabin thought it necessary to separate two types of carbonatite occurrence: (a) the platform type, associated with the complexes of ultrabasic-alkaline rocks, and (b) the geosynclinal type, associated with alkaline complexes of nepheline syenites, the origin of which is dependent on geosynclinal magmatism. More recently, Barker (1969) in a study of more than 120 occurrences of feldspathoid-bearing rocks in North America, stated that only a third occurred in the stable cratonic areas. The remainder are located in Phanerozoic fold belts.

Many investigators have suggested structural controls for the emplacement of alkaline complexes and Heinrich (1966) gives a synopsis of these suggestions. Ginzburg (1962), for example, has pointed out that the age of alkaline complexes near the edge of shields or platforms and the age of the folded area that bounds the platform are commonly close. According to Ginzburg, marginal fault zones controlled the emplacement of platform alkaline complexes and these fault zones are the result of intense tectonic disturbances in the adjacent geosyncline or folded area. King and Sutherland (1960) and Bailey (1961; 1964) among others mention the spatial association of alkaline rocks with the African rift system. Bailey (1964, p. 1107), however, pointed out that the relationship was not necessarily one of cause and effect but that it was just as likely that "rifting and magmatism are both expressions of a more fundamental process." In a study in eastern Canada, Kumarapeli (1970) concluded that post-Ordovician tectonic activity along the St. Lawrence rift system and the magmatism of the Monteregian Hills alkaline province are broadly synchronous. Miser (1934) and more recently Erickson and Blade (1963) state that the regional belt of alkaline undersaturated rocks that extends from West Texas to Central Mississippi lies within or near the boundaries of the Quachita geosyncline and this structure acted as a zone of weakness for the emplacement of alkaline rocks.

The occurrence of the western Alaska alkaline rocks in a belt which trends obliquely across the boundary between two geologic provinces with quite different tectonic style suggests a structural control. This boundary, though largely concealed beneath Quaternary basalt, has been mapped as a fault over much of its length (Patton, 1967) and Sainsbury (1969, p. 2595) states that it is locally a thrust fault with metamorphosed Paleozoic carbonate rocks thrust eastward over Cretaceous rocks. Although locally, or even extensively, this boundary may be a thrust fault, it probably represents a zone of major tectonic activity in this part of Alaska and may have been a zone of structural weakness along which deep-seated alkaline magma was emplaced.

LATE CRETACEOUS PLUTONIC SUITE

The Late Cretaceous suite of plutonic rocks forms the easternmost 80 miles of the Hogatza plutonic belt. The suite consists of three large bodies, the Zane Hills pluton, the Wheeler Creek pluton, and the Indian Mountain pluton, and two smaller masses at Mt. George and McLanes Creek (plate 1). Most of the field work was done on the three larger bodies, particularly the first two, and the discussion to follow will be concerned largely with these plutons. A petrographic summary of the suite is contained in table 10.

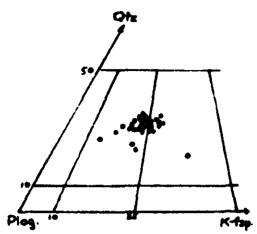
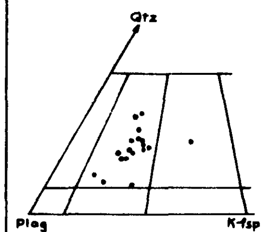
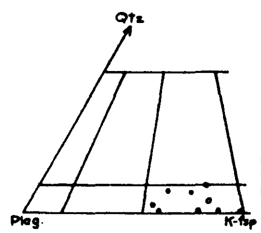
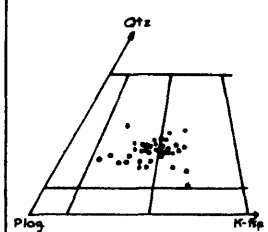
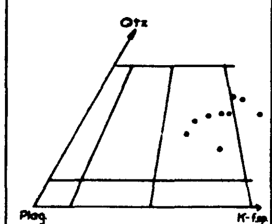
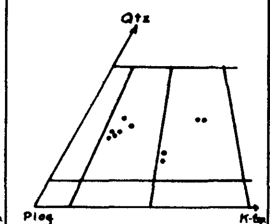
The Zane Hills, Indian Mountain, Mt. George, and McLanes Creek plutons are composed chiefly of granodiorite and quartz monzonite with a similar color, grain size, and texture. The typical rock is light gray leucocratic, generally medium-grained, hypidiomorphic and equigranular. The Wheeler Creek rocks, however, are noticeably different in texture and grain size from the other plutons. They consist of coarse-grained, porphyritic quartz monzonite and granodiorite and a generally coarse-grained, allotriomorphic granular alaskite.

Zane Hills and Wheeler Creek plutons

General character

The Zane Hills and Wheeler Creek plutons occur near the center of the Hogatza plutonic belt and form the core of the Zane Hills and Purcell Mountains (plate 3). The plutons underlie areas

Table 10. Petrographic summary of the Late Cretaceous plutonic suite.

		Zone Hills pluton			Wheeler Creek pluton		Indian Mountain pluton and satellitic bodies
Lithology of mapped units		biotite granodiorite	hornblende-biotite granodiorite	monzonite	porphyritic quartz monzonite and granodiorite	alaskite	hornblende-biotite granodiorite and quartz monzonite
Color index		4 – 7	7 – 15	10 – 40	10-20		10-20
COMPOSITION	Mafic minerals[1]	biotite[2]	biotite, hornblende[3], rare relic clinopyroxene	hornblende, clinopyroxene[4], biotite	hornblende, biotite	biotite	hornblende, biotite; clinopyroxene in satellitic dikes
	Plagioclase composition	calcic oligoclase-sodic andesine (An_{22-35})	calcic oligoclase - andesine (An_{25-40})	oligoclase (An_{20-25})	sodic to calcic andesine (An_{33-45})	albite-oligoclase (An_{8-10})	oligoclase to labradorite (An_{27-60})
	Ubiquitous accessories	apatite, sphene, magnetite, zircon, allanite					
	Other accessories	black tourmaline and, rarely, pink garnet found in aplite and alaskite dikes		uranothorianite (?)			
	Modal Composition						
TEXTURE	Grain size	medium to coarse	fine to medium	medium to coarse	medium to coarse	fine to coarse	medium
	Fabric	massive, hypidiamorphic and equigranular	massive, hypidiomorphic and equigranular; slightly gneissic at northern border.	porphyritic, gneissic, trachytoid	porphyritic	massive, allotriomorphic granular	massive, hypidiomorphic and equigranular
	Plagioclase with oscillatory normal zoning	common	common	rare	common	normal zoning only	common
Characteristic features		abundant large gray quartz anhedra; massive and coarse-grained fabric	similar to biotite granodiorite but finer-grained, less quartz	large K-feldspar phenocrysts; trachytoid to gneissic fabric	large cream-colored feldspar phenocrysts; numerous inclusions	large smoky quartz anhedra	

1 Predominant varieties underlined

2 Biotite characteristically X, pale yellow, Z = dark reddish brown

3 Hornblende X = light yellow green, Y = green, Z = blue-green, $Z \wedge C = 17-25°$

4 Clinopyroxene is colorless to light green

of 180 and 270 square miles respectively, and are separated by andesitic country rock and alluvium. The plutonic rocks are predominantly leucocratic granodiorite and quartz monzonite but include rocks ranging from hybrid diorite and monzonite to alaskite and aplite. The country rocks are chiefly andesite and dacite and range in age from Early to Late Cretaceous. Three K/Ar age determinations (table 2) on the plutonic rocks range from 78 to 82 m.y., indicating that the plutons were emplaced in Late Cretaceous time.

The Zane Hills pluton is composed of four principal rock types (plate 3) mapped on the basis of texture and(or) composition. These are granodiorite, comprising about 90 percent of the pluton and subdivided into hornblende-bearing and hornblende-free varieties, a unit of foliated monzonite and hybrid diorite found in two localities along the south and east sides of the pluton, and porphyritic quartz monzonite and granodiorite identical to that forming most of the Wheeler Creek pluton. The contact between the granodiorite units is gradational; contacts between the other units appear to be relatively sharp. Aplite and alaskite dikes are common throughout the pluton, particularly near the contacts, but have not been mapped separately. Locally these dikes have been intruded along joints.

The Wheeler Creek pluton consists of two principal rock types: (1) coarse-grained porphyritic quartz monzonite and granodiorite which underlies about 240 square miles of the pluton, and (2) coarse-grained alaskite which forms the west end of the pluton and covers an area of about 30 square miles. Similar alaskite dikes cut the porphyritic quartz monzonite and granodiorite indicating the alaskite is the younger. Autolithic inclusions up to several inches across are common throughout the porphyritic quartz monzonite, in contrast to the granodiorite of the Zane Hills. No obvious foliation and lineation were observed in either the porphyritic quartz monzonite or the alaskite.

Both plutons are discordant bodies with sharp, steeply dipping contacts except at the north end of the Zane Hills pluton where the contact appears to slope gently northward. Thermal effects in the andesite can be recognized up to a half mile from the pluton. Hornblende hornfels facies assemblages commonly including large hornblende porphyroblasts are typical of the immediate contact zone.

The plutonic rocks are medium- to coarse-grained and lack obvious flow structures or lineations except in the foliated monzonite and in the hornblende-biotite granodiorite of the Zane Hills pluton next to the country rock contact.

The Shinilikrok River volcanic complex (plate 3) is the youngest unit intruded by the plutons and the K/Ar ages suggest only a short time separated pre-pluton volcanism and intrusion of the plutons. This short time interval plus similar compositions and a close spatial relationship between the dacite and the quartz monzonite of the Wheeler Creek pluton, suggests the volcanic complex was an early stage of the Wheeler Creek magmatic episode.

The association of volcanic rocks with plutonic rocks of the same general age and composition, together with many of the features mentioned above meet many of Buddington's (1959) criteria for plutons emplaced at relatively shallow depth in the epizone.

Petrography and chemistry

Granodiorite of the Zane Hills.--The southern half of the Zane Hills pluton consists of leucocratic coarse-grained biotite granodiorite and quartz monzonite with a hypidiomorphic equigranular texture (figs. 21 and 22). This massive, nonfoliated rock is monotonously uniform in composition over its entire outcrop area. Average modes and the standard deviations for all the plutonic rocks are given in table 11; the average of 36 stained slab modes for the biotite granodiorite is 28.7 percent quartz, 44.0 percent plagioclase, 21.5 percent K-feldspar, and 5.9 percent mafic minerals; a granodiorite but close to being a quartz monzonite. The plot of the felsic modal components shows a relatively tight grouping around the boundary between the granodiorite and quartz monzonite fields (table 11). The homogeneity of the biotite granodiorite is also reflected in the relatively small standard deviations of the various mineral components.

The plagioclase in the biotite granodiorite occurs as large subhedral crystals exhibiting well-developed oscillatory zoning throughout most of the crystal with a narrow rim of normally zoned material. Vance (1962) in a study of zoning of igneous plagioclase

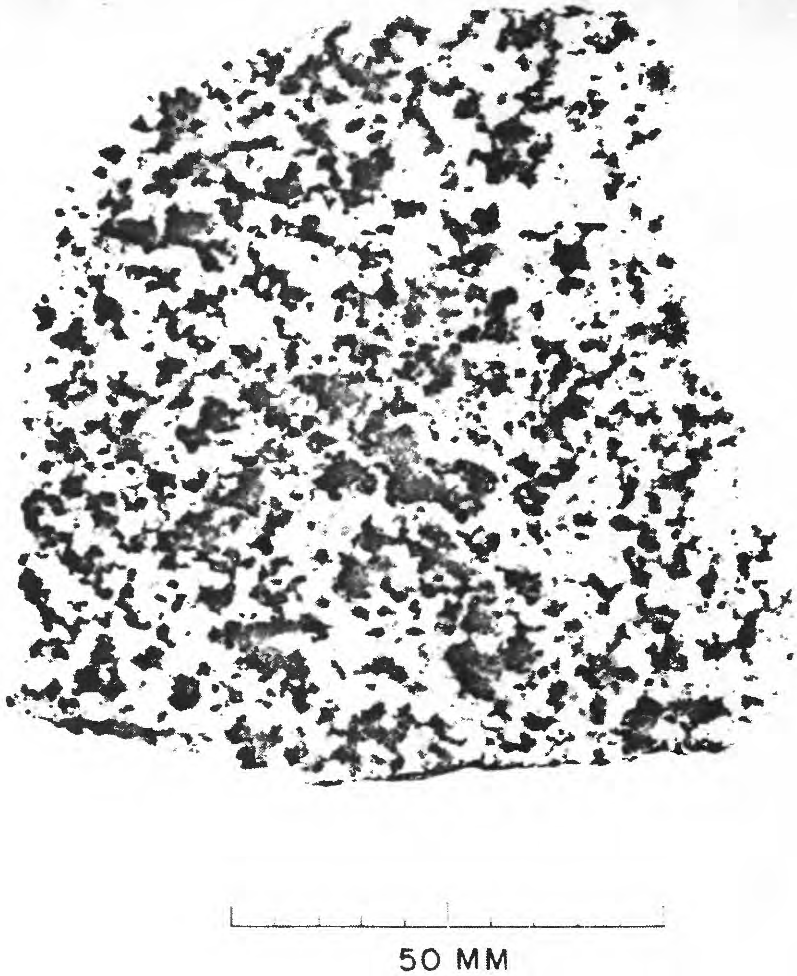


Figure 21. Typical hand specimen of biotite granodiorite from the Zane Hills pluton.

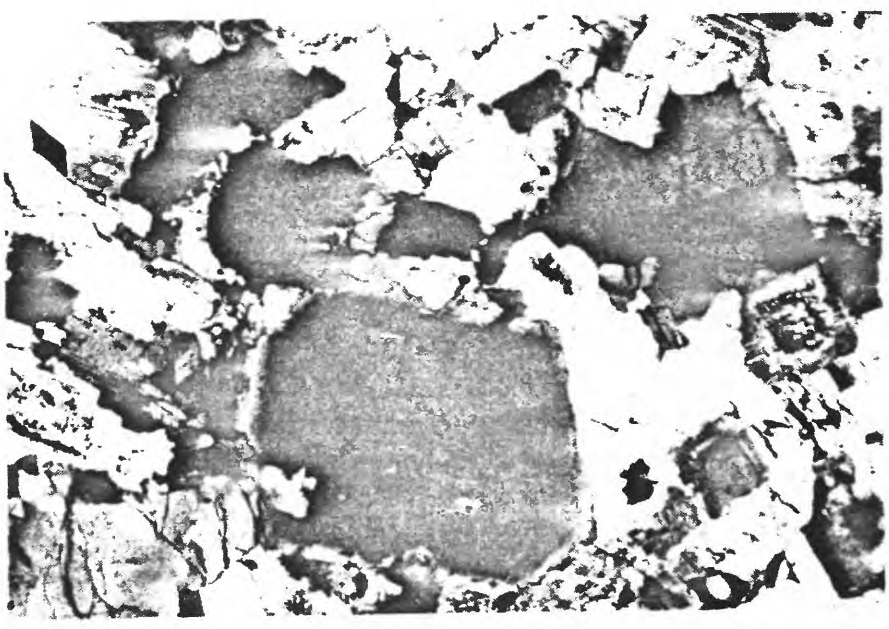


Figure 22. Photomicrograph of above specimen showing zoned plagioclase and granitic texture.

Table 11. Summary of modal data from the principal units of the Zane Hills and Wheeler Creek plutons.

	Parameter	Quartz	Plagioclase	K-feldspar	Mafic minerals	No. of analyses
Biotite granodiorite (Zane Hills pluton)	Avg.	28.7	44.0	21.5	5.9	36
	Std. Dev.	3.1	4.1	4.0	1.3	
Hornblende-biotite granodiorite (Zane Hills pluton)	Avg.	21.2	48.8	17.1	12.2	20
	Std. Dev.	6.4	5.6	4.2	4.2	
Hornblende-biotite quartz monzonite (Wheeler Creek pluton)	Avg.	18.9	43.1	23.1	14.9	37
	Std. Dev.	4.2	4.4	5.6	4.4	

concluded that oscillatory zoning formed in response to recurrent supersaturation of the melt in anorthite adjacent to individual crystals. When the melt became saturated in volatiles, agitation by the escaping volatiles maintained a uniform melt composition equalizing rates of diffusion and crystallization. Such a process is reflected in the normally zoned rims. The low rim to core ratio in the present case suggests that the melt was saturated with volatiles only after most of the plagioclase had crystallized. The range of composition as determined by extinction angles on albite twins is from about An_{35} to An_{22} (sodic andesine to calcic oligoclase). Myrmekite is abundant at contacts between plagioclase and K-feldspar. Quartz forms large (up to 1 cm) anhedra which show undulatory extinction. K-feldspar generally shows typical microcline twinning and is commonly perthitic. Biotite occurs as large euhedral flakes with slight to moderate alteration to chlorite and less commonly epidote.

Most of the northern half of the pluton consists of hornblende-biotite granodiorite. The contact with the biotite granodiorite was located where hornblende constitutes more than 1 percent of the rock (plate 3). In contrast to the compositionally homogeneous biotite granodiorite, the northern part of the pluton shows a gradational change in composition form south to north. The hornblende content gradually increases although it is generally less than biotite. Quartz and K-feldspar decrease and plagioclase and the total mafic mineral content gradually increase. The plagioclase is slightly more calcic, An_{38-40}, than in the biotite granodiorite. Rarely, and only at the extreme northern end of the pluton adjacent to the andesite country rock, relict clinopyroxene cores in hornblende are observed. The average mode of the hornblende-biotite granodiorite (table 11) is 21 percent quartz, 49 percent plagioclase, 17 percent K-feldspar, and 12 percent mafic minerals. The modes all plot in the granodiorite field (table 10) and show a greater scatter than the biotite granodiorite modes. This scatter is also reflected in the standard deviations (table 11).

A change in grain size also occurs across the northern part of the pluton. The grain size decreases to the north and the hornblende-biotite granodiorite is fine- to medium-grained in contrast to the generally coarse-grained biotite granodiorite.

Rapid rock chemical analyses of seven samples of granodiorite from the Zane Hills pluton are shown in table 12. Specimens 1, 2, and 3 are from the biotite granodiorite and have modes close to the average mode of the biotite granodiorite; since the standard deviations of the modes in table 11 are relatively small, the average of the analyses of these three specimens is thought to be close to the average chemical composition of the unit. This average compared to Nockolds' (1954) average of 36 biotite granodiorite analyses (table 12) has less FeO, MgO, and CaO and somewhat greater SiO_2. These differences are probably due to the low content of mafic minerals in the biotite granodiorite of the Zane Hills.

Table 12. Chemical data for the Late Cretaceous plutonic suite, west-central Alaska

Rapid rock chemical analyses (weight percent)

	Zane Hills pluton								Wheeler Creek pluton						Shinilikrok R. volcanic complex		Indian Mtn. pluton and satellitic dikes						Avg. biotite granodiorite (Nockolds, 1954)	Avg. biotite granodiorite of Zane Hills pluton
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22		
SiO_2	71.6	71.2	71.5	69.3	69.9	67.9	65.8	61.1	67.2	65.6	64.9	64.6	63.3	77.4	65.9	65.1	66.8	66.8	62.2	72.7	66.4	67.8	68.97	71.4
Al_2O_3	14.8	15.2	14.9	15.4	15.8	17.0	15.6	19.0	15.2	15.4	16.2	16.0	15.6	12.1	16.1	15.6	16.4	16.6	16.4	13.9	16.3	15.2	15.47	15.0
Fe_2O_3	1.7	.90	1.0	1.2	1.0	1.2	1.1	1.7	1.6	1.7	1.9	1.7	2.3	.60	1.7	3.1	1.4	1.5	2.3	1.1	1.2	1.3	1.12	1.2
FeO	0.8	1.0	1.0	1.4	1.3	1.5	2.3	1.6	1.6	1.9	1.8	1.9	2.4	.26	1.2	.34	1.8	1.5	2.6	.96	1.6	.96	2.05	0.9
MgO	0.6	.77	.62	1.0	1.0	1.3	1.9	.83	1.7	2.3	2.1	2.0	3.0	.09	1.4	2.0	1.5	1.5	2.4	.50	1.7	1.3	1.15	.67
CaO	2.1	2.7	2.2	2.7	2.8	3.5	3.6	2.8	3.3	3.7	3.8	3.8	4.4	.49	3.0	3.0	4.2	4.2	5.0	2.2	3.8	3.5	2.99	2.3
Na_2O	3.8	3.8	3.9	3.9	4.0	4.0	4.2	5.3	3.8	3.5	3.5	3.9	3.7	4.1	4.0	3.8	3.9	4.1	3.8	3.2	4.0	3.9	3.69	3.8
K_2O	3.5	2.7	3.7	2.8	3.0	2.2	3.6	6.3	3.7	3.2	3.9	3.2	3.0	3.8	3.3	3.0	1.8	1.9	3.2	4.4	1.8	1.8	3.16	3.3
H_2O-	.05	.02	.03	.05	.05	.02	.16	.06	.15	.33	.11	.44	.11	.02	.20	.28	0.4	.13	.13	0.0	.23	.66	---	.03
H_2O+	.51	.58	.45	.68	.57	.57	.53	.67	.60	.77	.62	1.4	.89	.35	1.5	1.6	.82	.74	.70	.48	1.8	2.2	.70	.51
TiO_2	.23	.26	.25	.38	.33	.38	.58	.39	.47	.49	.53	.54	.65	.14	.40	.54	.42	.36	.78	.32	.36	.29	.45	.25
P_2O_5	.08	.12	.10	.16	.15	.19	.33	.16	.24	.35	.31	.29	.39	0.0	.21	.35	.23	.18	.32	.11	.22	.12	.19	.10
MnO	.06	.05	.05	.07	.06	.07	.13	.07	.04	.10	.11	.07	.09	.05	.09	.06	.10	.06	.06	.00	.07	.05	.06	.05
CO_2	<.05	<.05	.11	<.05	.07	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	<.05	.49	.58	<.05	.09	.08	<.05	<.05	.12	---	.03
Sum	100	99	100	99	100	100	100	100	100	99	100	100	100	99	99	99	99	100	100	100	99	99	(36 analyses)	

Semiquantitative spectrographic analyses (ppm)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
B	0	0	15	0	10	10	0	0	0	0	0	0	10	15	10	0	0	0	10	15	10	10
Ba	2000	2000	1000	2000	2000	2000	3000	1500	2000	1500	2000	2000	2000	200	2000	2000	2000	2000	2000	2000	2000	2000
Be	2	1.5	2	2	1.5	1.5	0	3	0	1.5	0	0	2	5	2	1.5	0	1.5	2	1.5	0	0
Ce	0	0	0	0	0	150	200	200	0	100	150	0	100	0	200	200	0	0	150	0	0	0
Co	5	5	5	7	7	10	10	7	10	15	10	10	20	0	10	10	10	10	20	7	10	7
Cr	7	5	7	10	10	15	30	10	70	50	50	70	70	0	20	70	15	15	50	20	20	15
Cu	15	10	20	30	15	20	15	20	50	70	15	20	30	7	30	50	15	5	50	100	20	20
Ga	15	15	30	20	20	20	20	20	15	15	20	15	20	0	20	15	20	20	15	15	15	15
La	50	50	30	100	50	70	100	150	70	70	100	70	70	0	100	100	0	70	100	50	70	30
Nb	10	10	15	15	10	10	10	20	7	15	15	10	15	50	10	15	10	10	30	20	10	0
Ni	7	5	7	10	7	15	30	7	50	50	30	50	70	0	20	50	15	20	50	20	30	15
Pb	70	30	70	50	50	50	50	70	20	30	30	50	30	50	70	50	20	20	20	30	20	30
Sc	3	5	5	7	7	7	7	50	7	10	10	10	15	0	7	10	10	10	15	7	7	7
Sr	500	500	300	700	700	1000	1500	1000	700	1500	1500	1000	1500	500	1000	1500	700	1000	1000	300	1500	1000
V	30	50	50	70	50	100	70	100	150	100	70	100	150	10	100	100	100	100	200	70	70	50
Y	15	15	10	20	20	20	10	30	10	20	15	15	20	20	20	15	10	7	30	15	10	7
Yb	1	1.5	1.5	2	1.5	2	1	2	1.5	1.5	1.5	1.5	2	2	2	2	1	1	3	1.5	1.5	0
Zr	100	150	100	200	200	100	100	200	100	100	100	100	200	150	100	150	150	100	200	200	150	100

Looked for but not found: Ag, Sn, W

Table 12--continued

CIPW Norms (weight percent)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
q	31.3	32.4	29.5	29.2	28.0	27.1	17.4	0.0	22.0	22.4	18.8	18.9	17.4	38.3	23.8	25.3	26.4	25.0	14.9	32.3	26.3	30.4
or	20.8	16.2	22.0	16.8	17.8	13.1	21.3	37.3	22.0	19.2	23.1	19.0	17.9	22.7	19.9	18.2	10.8	11.4	19.1	26.1	10.9	11.0
ab	32.4	32.6	33.2	33.6	34.0	34.1	35.6	44.9	32.3	30.1	29.7	33.2	31.7	35.0	34.6	33.0	33.5	35.1	32.4	27.2	34.7	34.3
an	9.6	12.4	9.6	12.2	12.3	15.9	13.1	9.5	13.6	16.4	16.9	16.8	17.3	2.1	10.6	9.2	19.3	19.3	18.4	9.9	17.5	16.4
c	1.3	1.5	1.0	1.6	1.5	2.3	--	--	--	0.3	0.1	--	--	0.5	2.2	2.9	1.1	0.8	--	0.3	1.5	1.1
wo	--	--	--	--	--	--	1.1	1.4	0.6	--	--	0.1	0.9	--	--	--	--	--	1.7	--	--	--
en	1.5	1.9	1.6	2.5	2.5	3.3	4.7	1.2	4.3	5.8	5.2	5.0	7.6	0.2	3.6	5.1	3.8	3.8	6.0	1.3	4.3	3.4
fs	--	0.8	0.7	1.1	1.0	1.3	2.6	0.6	0.9	1.5	1.1	1.3	1.6	--	0.3	--	1.7	1.0	1.7	0.3	1.5	0.3
mt	2.1	1.3	1.5	1.8	1.5	1.8	1.6	2.5	2.3	2.5	2.8	2.5	3.4	0.6	2.5	--	2.1	2.2	3.4	1.6	1.8	2.0
il	0.4	0.5	0.5	0.7	0.8	0.7	1.1	0.7	0.9	0.9	1.1	1.0	1.2	0.3	0.8	0.9	0.8	0.7	1.5	0.6	0.7	0.6
ap	0.2	0.3	0.2	0.4	0.4	0.5	0.8	0.4	0.6	0.8	0.7	0.7	0.9	--	0.5	0.9	0.6	0.4	0.8	0.3	0.5	0.3
cc	--	--	0.3	--	0.2	--	--	--	--	--	--	--	--	--	1.1	1.4	--	0.2	0.2	--	--	0.3
DI	84.5	81.2	84.7	79.6	79.8	74.3	74.4	82.2	76.3	71.7	71.6	71.2	67.0	96.0	78.3	76.5	70.7	71.5	66.4	85.6	71.9	75.7

Modes (volume percent)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Quartz	29.9	28.2	29.0	22.3	30.9	26.8	22.9	0.0	21.8	25.2	19.0	21.8	17.5	32.2	--	--	26.2	22.3	14.9	29.3	--	--
Plagioclase	45.1	45.9	42.6	50.3	41.6	51.6	33.7	42.6	37.7	36.9	43.4	36.9	44.3	46.7	--	--	49.0	57.0	39.4	31.5	--	--
K-feldspar	20.8	20.6	22.7	20.0	13.6	13.7	30.9	45.5	29.2	24.2	26.6	30.9	19.4	20.4	--	--	12.4	9.5	22.7	32.7	--	--
Total Mafic Min.	4.2	5.3	5.7	7.4	13.6	7.8	12.5	11.9	11.3	13.7	10.9	10.3	18.8	0.7	--	--	12.4	11.7	23.0	6.6	--	--
(Biotite)	(3.5)	(4.6)	(5.0)	(6.2)	(7.3)	(5.6)	(4.0)	(0.0)	--	--	--	(4.2)	(4.2)	(0.3)	--	--	(8.8)	(8.0)	(7.6)	(2.8)	--	--
(Hornblende)	(--)	(0.5)	(--)	(0.3)	(6.1)	(1.8)	(7.8)	(11.5)	--	--	--	(5.7)	(14.2)	(--)	--	--	(3.0)	(3.1)	(13.0)	(3.5)	--	--
(Met. opaques)	(0.7)	(0.1)	(0.7)	(0.6)	(0.2)	(0.4)	(0.2)	(0.4)	--	--	--	(0.4)	(0.4)	(0.4)	--	--	(0.6)	(0.6)	(2.4)	(0.3)	--	--
Other accessories	0.1	0.1	--	0.3	0.1	0.1	0.5	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Rock type

1 Biotite granodiorite
2 Biotite granodiorite
3 Biotite granodiorite
4 Biotite granodiorite
5 Hornblende-biotite granodiorite
6 Hornblende-biotite granodiorite
7 Hornblende-biotite quartz monzonite
8 Monzonite
9 Hornblende-biotite quartz monzonite
10 Hornblende-biotite quartz monzonite
11 Hornblende-biotite quartz monzonite
12 Hornblende-biotite quartz monzonite
13 Hornblende-biotite granodiorite
14 Alaskite
15 Dacite
16 Dacite
17 Hornblende-biotite granodiorite
18 Hornblende-biotite granodiorite
19 Biotite-hornblende quartz monzonite
20 Biotite-hornblende quartz monzonite
21 Dacite dike
22 Dacite dike

Specimens 5, 6, and 7 are of hornblende-biotite granodiorite from the northern part of the pluton. Modal hornblende in these rocks ranges from 2 to 8 percent and the total mafic minerals from 8 to 14 percent (table 12). With respect to the biotite granodiorite these modal percentages are reflected in lower SiO_2 and higher FeO, MgO, and CaO in the hornblende-biotite granodiorite.

The compositional and textural zoning in the pluton is so gradual that it does not seem likely that it is due to separate intrusions. The lack of concentric zoning indicates that the zoning is not due to cooling of an intrusion from the walls toward the center. If the pluton is considered in cross-section, however, a possible explanation is seen for the lateral zoning. The map pattern in the northern part of the pluton shows that the contact slopes at a moderate angle to the north (plate 3) and the extent of thermally metamorphosed country rock north of the pluton suggests that a considerable part of the northern Zane Hills is underlain by plutonic rocks at no great depth. This area also has numerous sulfide-bearing quartz veins and hypabyssal porphyritic intrusives (Miller and Ferrians, 1968). The pluton thus appears to have an asymmetric profile along a northwest-southeast section as indicated in plate 3. Since the granodiorite gradually becomes more mafic and fine-grained towards the northern contact, it would appear that the pluton cooled gradually from the top. The roof zone of the pluton may well have been slightly contaminated by andesite country rock, but the lack of country rock inclusions suggests any major assimilation took place at greater depth and reaction between magma and country rock was complete prior to the magma reaching its present level. The slightly more mafic magma of the roof zone crystallized at a more rapid rate than the underlying magma, resulting in the finer grained hornblende-biotite granodiorite.

Monzonite of the Zane Hills pluton.--Two small bodies of porphyritic (fig. 23) to gneissic monzonite occur along the south and east sides of the Zane Hills pluton. The unit is heterogeneous in composition, texture, and grain size and was mapped on this basis since the adjacent granodiorite is typically massive and equigranular. The contact with the granodiorite is abrupt but, owing to the poor outcrop, mutual relationships are not known. The contact between monzonite and country rock is not as abrupt as country rock contacts elsewhere in the pluton but, rather, is marked by a zone of andesitic hornfels and contact schists mixed with mesocratic monzonite that is as wide as several hundred yards. The monzonite at the south end of the pluton includes large areas of hybrid diorite thought to have formed by assimilation of andesite country rock.

K-feldspar in the monzonite typically occurs as large (up to 3 inch) euhedral to subhedral phenocrysts of perthitic microcline (fig. 24) commonly including separate albite grains. Plagioclase occurs as unzoned anhedral of oligoclase (An_{20-25}) although a few relict(?) grains of andesine (An_{40}) were also found. Quartz is usually minor and interstitial. Hornblende is the most common

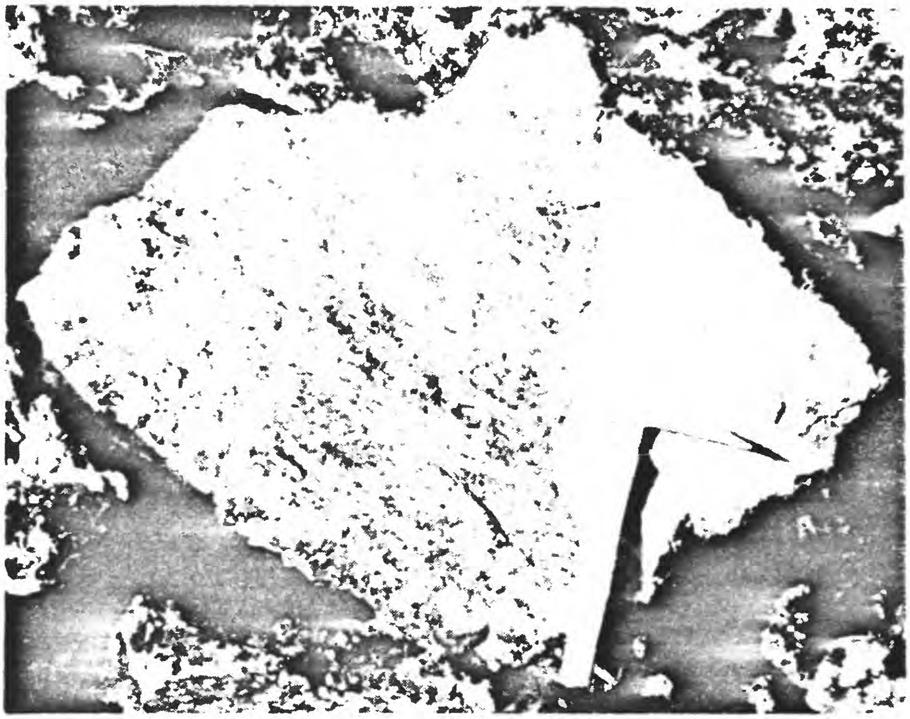


Figure 23. Porphyritic monzonite of the Zane Hills pluton; cut by tourmaline-bearing aplite dike.

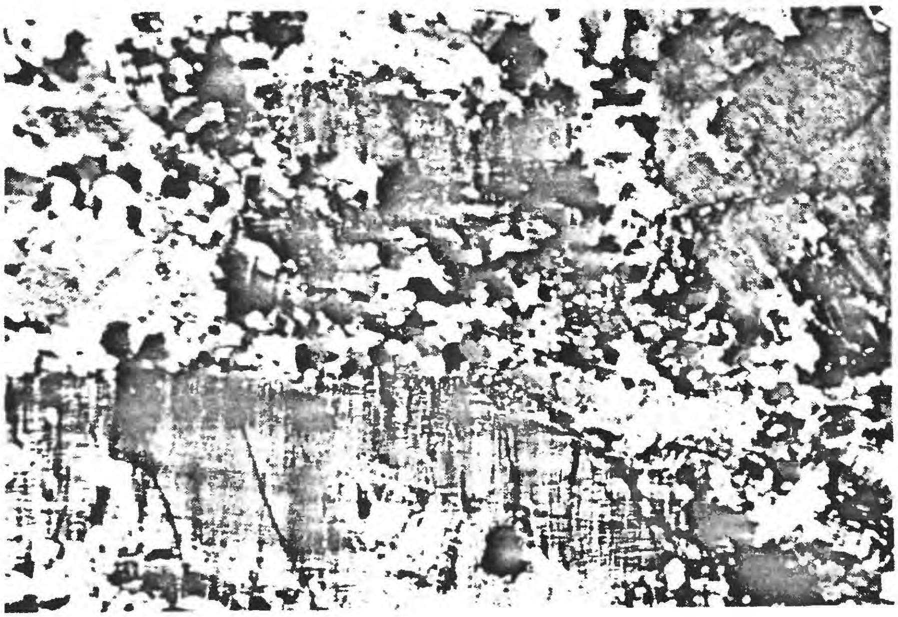


Figure 24. Photomicrograph of monzonite showing allotriomorphic granular texture (12X).

mafic mineral and appears to be an iron and alkali-rich variety. Diopsidic augite occurs commonly as scattered euhedra and as relics in hornblende; biotite is relatively rare.

The texture of the monzonite ranges from porphyritic to gneissic allotriomorphic granular. The phenocrysts are microcline and perthite and range from large tabular euhedra to subhedra with ragged edges. In the more gneissic rocks, the groundmass is a mosaic of granulated feldspar and quartz anhedra.

The hybrid diorite in this unit probably formed by assimilation of andesite country rock. However, the abundance of K-feldspar, particularly in large phenocrysts, together with many of the textural features described above suggest potassium metasomatism. This metasomatism affected not only the intrusive rock but also, at least locally, the andesite, as shown by the sporadic occurrence of large K-feldspar porphyroblasts in the latter.

The presence of both planar flow structures and crushing features suggests the monzonite was deformed during the last stages of crystallization. The potassium metasomatism took place somewhat earlier, judging from the deformation of some of the K-feldspar phenocrysts. Mutual relationships between granodiorite and monzonite are not known; however, aplite dikes are common in both units. These aplite and alaskite dikes may have been derived from a residual granitic magma fraction after the emplacement of the granodiorite magma adjacent to the monzonite.

A chemical analysis of a typical monzonite (no. 8, table 12) reflects the lower quartz and higher alkali feldspar content as compared to the granodiorite. SiO_2 is lower in the monzonite and K_2O is about twice that of the granodiorite; Na_2O and Al_2O_3 are also noticeably greater than the granodiorite.

An interesting feature of the monzonite is its high radioactivity relative to the surrounding rocks. A hand-held scintillometer survey showed that the radioactivity of the monzonite was generally 5 to 10 times greater than that of the granodiorite. Attempts to locate the radioactive mineral(s) in thin section and by mineral separation were unsuccessful. At the suggestion of C. W. Naeser, a thin section of an analyzed monzonite sample containing 20 ppm uranium (5 to 6 times higher than average granitic rocks; Smith, 1963; Green, 1959) was exposed to a thermal neutron beam in a reactor to cause the fission of U^{235}. The fission events were recorded in a piece of lexan which covered the section. Comparison of the thin section with the intensity of fission tracks in the lexan showed the uranium to be concentrated in very small grains of an isotropic mineral of high relief. The mineral is disseminated as an accessory mineral and has a euhedral cubic-like crystal form. The presence of anomalous amounts of thorium (200 ppm) in a panned concentrate from Caribou Creek (plate 3) which drains the monzonite (Miller and Ferrians, 1968) suggests that this mineral may be uranothorianite.

Aplite and alaskite of the Zane Hills.--Dikes and small bodies of aplite and alaskite occur throughout the pluton but are particularly common near the contacts and in the monzonite. Black tourmaline is a common constituent, particularly in aplite cutting the monzonite; locally it constitutes as much as 10 percent of a hand-sized specimen. Much less common are pink garnet euhedra which occur in some of the alaskite; these are probably spessartine-almandites.

The aplite has its characteristic sugary texture while the alaskite is coarser grained with a wide range in grain size and degree of crystallinity. Pegmatite-like lenses and pods occur locally in both rock types. Granophyre showing a very well-developed long cuneiform quartz lenses in either K-feldspar or albite is common in the alaskite.

The alaskite of the Zane Hills does not contain the black smoky quartz anhedra characteristic of the alaskite of the Wheeler Creek pluton.

Porphyritic quartz monzonite and granodiorite of Wheeler Creek pluton.--Most of the Wheeler Creek pluton is composed of porphyritic quartz monzonite and granodiorite, with prominent white euhedral plagioclase phenocrysts up to 2 cm long (fig. 25). Smaller pink K-feldspar and gray quartz anhedra are also readily observed in hand specimen together with abundant hornblende and biotite. The rock is medium- to coarse-grained with a uniform non-oriented porphyritic texture. The average mode of 38 analyses

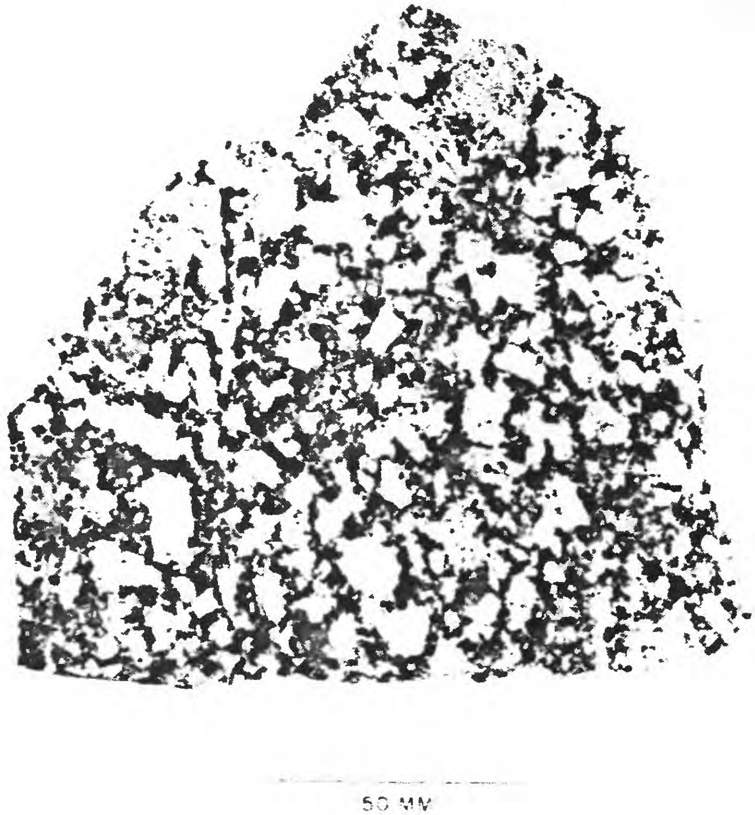


Figure 25. Porphyritic quartz monzonite of the Wheeler Creek pluton; note large white plagioclase phenocrysts.

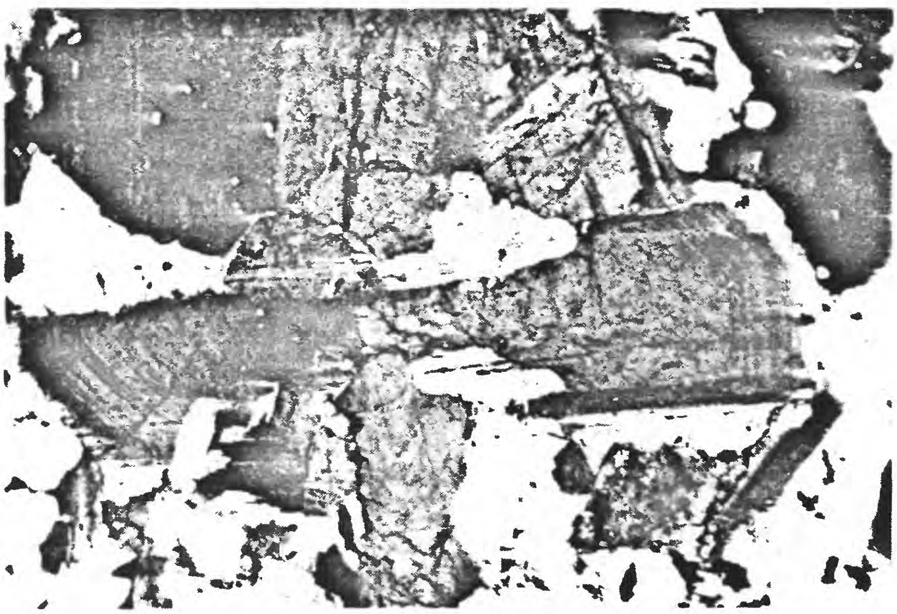


Figure 26. Photomicrograph of above specimen; note oscillatory zoning in large plagioclase phenocrysts (1[illegible]).

(table 11) is 18.8 percent quartz, 44 percent plagioclase, 23 percent K-feldspar, and 16 percent mafic minerals. The average composition is a quartz monzonite but the composition of the unit ranges over a considerable portion of both the quartz monzonite and granodiorite fields (table 10). The sample density of this unit is low, about half that of the Zane Hills pluton. However, the modal plot (table 10) shows a fairly well defined linear trend, at least part of which represents a change in composition that appears to take place across the pluton from east to west. The easternmost rocks of this unit, including those in the northwest corner of the Zane Hills pluton, have a high mafic content, up to 26 percent and quartz is as low as 14 percent. The mafic content decreases eastward and the quartz content increases; the change appears to be gradational. The lowest mafic content and the highest quartz content occur adjacent to the alaskite at the west end of the pluton. The contact between these units is not, however, gradational.

The large euhedral phenocrysts of plagioclase show strong oscillatory zoning (fig. 26) and a compositional range from An_{45} to An_{33} (calcic to sodic andesine) for much of an individual crystal and compositions as low as An_{28} (calcic oligoclase) for the narrow rims. The K-feldspar is subhedral to anhedral and perthitic; grid-twinning, in contrast to the granodiorite of the Zane Hills, is rare. Quartz is subhedral and interstitial. Hornblende and biotite are the varietal mafic minerals, hornblende generally being about twice as abundant as biotite.

Chemical analyses were obtained on five samples from this unit (table 12) whose modes cluster near the average mode of the unit. Comparison of these five specimens with Nockolds (1954) average of 65 hornblende-biotite granodiorites shows a fairly close agreement. Compared to the granodiorite of the Zane Hills, the Wheeler Creek rocks are noticeably poorer in SiO_2, and richer in Fe_2O_3, FeO, MgO, and CaO. This is to be expected from the modal differences between the two units.

The area underlain by the pluton declines in elevation from west to east and the pendant-like nature of the andesite near Fidget BM on the east side of the pluton suggests that the roof of the eastern part of the pluton was at a lower elevation than in the west. The indicated zoning in the quartz monzonite of the Wheeler Creek pluton is similar to that described for the Zane Hills pluton and perhaps was also caused by contamination.

Alaskite of the Wheeler Creek pluton.--Coarse-grained alaskite underlies the west end of the Wheeler Creek pluton (plate 3) and intrudes rocks ranging from Lower Cretaceous andesitic volcanics to the Upper Cretaceous dacitic hypabyssal rocks. Alaskite outcrops are characterized by rounded pink-colored hills with little vegetation and a mantle of grus. The alaskite itself is characterized megascopically by large (up to 1 cm) black smoky quartz anhedra in a setting of pink feldspar anhedra (fig. 27). The rock is characteristically coarse-grained with an allotriomorphic granular texture. The abundance of the smoky quartz

Figure 27. Alaskite of the Wheeler Creek pluton; black anhedral grains are smoky quartz.

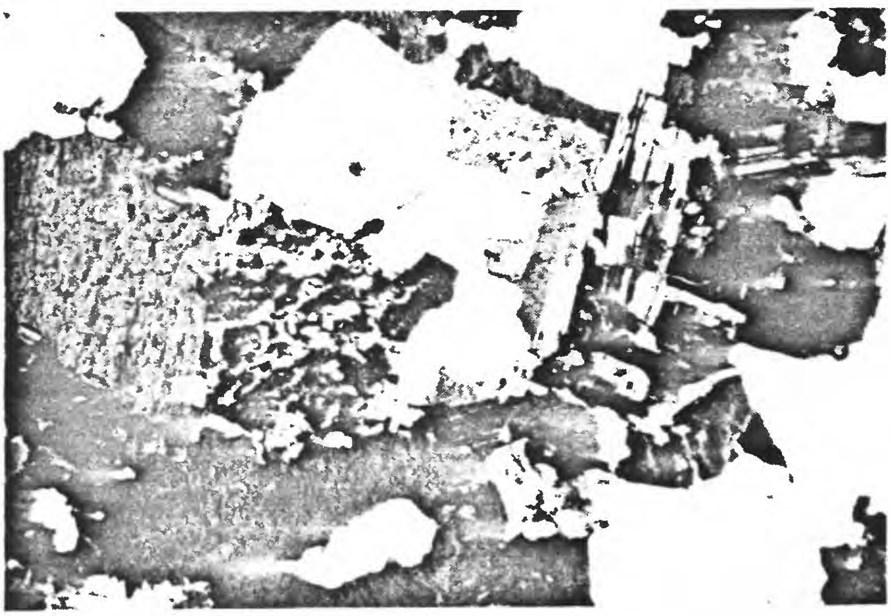


Figure 28. Photomicrograph of alaskite of the Wheeler Creek pluton showing abundant perthite (12X).

distinguishes this unit from the minor alaskite and aplite dikes that locally cut the Zane Hills pluton. The rock is generally a true alaskite, with less than 1 percent mafic minerals, although locally the mafic content reaches as much as 8 percent near the contact and in the alaskite dikes cutting the quartz monzonite-granodiorite to the east.

The K-feldspar is typically "patch" perthite and generally forms subhedral grains (fig. 28). Plagioclase occurs as euhedra with weak normal zoning; the composition is An_{8-10} (albite-oligoclase). Quartz occurs as large anhedra with undulatory extinction. Biotite is the principal mafic mineral but hornblende is present locally near country contacts.

A chemical analysis of alaskite is given in table 10 and shows the felsic nature of the rock. A striking difference between the norm and mode of the analyzed sample is the relative content of K-feldspar and plagioclase. The norm shows more plagioclase and less K-feldspar than the mode. The reason for this is probably solid solution of albite in K-feldspar; many alkali feldspar grains contain from a third to a half exsolved albite. On stained slab surfaces these alkali feldspar grains were counted as K-feldspar.

McLanes Creek pluton

This pluton is very poorly exposed in a heavily wooded and alluvium-covered area just above the floodplain of the Hogatza

River about 20 miles east of the Zane Hills (plate 1). Access even by helicopter was possible in only two places. Samples collected from these stations were leucocratic medium-grained hornblende-biotite granodiorite similar to that of the northern Zane Hills and Indian Mountain plutons.

Indian Mountain and Mt. George plutons and related hypabyssal rocks

General character

The Indian Mountain pluton underlies an area of about 80 square miles east of the Koyukuk River (plate 5) and forms the southern half of the Indian Mountains. Less field work has been done on this pluton than on the Zane Hills and Wheeler Creek plutons; however, reconnaissance mapping indicates that the pluton consists chiefly of hornblende-biotite granodiorite. It intrudes rocks as young as Late Cretaceous and a K/Ar age of 81.5 m.y. (table 2) has been obtained on hornblende from this pluton. The country rock contacts are sharp and steeply dipping. The pluton is surrounded by a resistant rim of contact hornfels, and a metamorphic aureole extends as far as a mile from the contact in places. In general, hornblende hornfels facies assemblages are found in the immediate contact zone; however, the occurrence of a hypersthene-cordierite-biotite assemblage in metatuff at the south end of the pluton indicates that a higher metamorphic grade was reached locally. Tourmaline-bearing aplite dikes are common cutting the pluton and the immediate country rock. The rather irregular map pattern of the Indian Mountain pluton with its numerous re-entrants suggests the pluton has a roof with considerable relief, similar to the Zane Hills and Wheeler Creek plutons.

The Mt. George pluton is located at the north end of the Indian Mountains; it has been visited only briefly and the few samples collected were similar to the granodiorite of the Indian Mountain pluton. The graywacke and mudstone of late Early Cretaceous (Albian) age between the two plutons is strongly indurated to hornfels and is cut by numerous small intrusive bodies and dikes suggesting that the area is underlain at no great depth by plutonic rocks.

A swarm of dacite and quartz latite dikes surrounds the pluton for a distance of up to 10 miles. These hypabyssal intrusives are generally less than 100 feet thick and are particularly common north and west of the pluton. The dikes are locally crosscutting indicating more than one period of activity. The mapped dikes shown on plate 5 represent only some of the many dikes in the area.

Petrography and chemistry

Hornblende-biotite granodiorite forms most of the Indian Mountain pluton and is typically a leucocratic, medium-grained massive rock with a hypidiomorphic, equigranular texture. Plagioclase occurs as euhedra exhibiting both oscillatory and normal zoning with a low rim/core ratio. The composition ranges from cores as calcic as An_{50} (calcic andesine) to rims of An_{27} (calcic oligoclase). K-feldspar is typically perthite and anhedral; very little twinned microcline was observed. Quartz is interstitial and anhedral. Hornblende and biotite are the varietal mafic minerals.

The hypabyssal rocks surrounding the pluton are chiefly medium-grained porphyritic dacite and quartz latite. Phenocrysts are usually plagioclase with strong oscillatory zoning and a composition as calcic as labradorite (An_{60}); groundmass plagioclase is somewhat more sodic. In places, the phenocrysts show resorption features. Hornblende and biotite occur as smaller phenocrysts commonly partly altered to chlorite and epidote. Clinopyroxene occurs in some of the more mafic varieties. Quartz and K-feldspar are generally confined to the aphanitic groundmass.

Plutonic rocks were not observed grading into the hypabyssal porphyries nor were the latter observed cutting the pluton. Rather, the pluton appears to have cut across the hypabyssal swarm and to be at least somewhat younger. The dikes and sills appear to have been concentrated above the roof of the pluton and were cut by large-scale emplacement of the magma. A smaller but similar swarm of porphyritic intrusions occurs in the Sun Mountain (plate 1) area 20 miles to the southwest. These intrusions intrude thermally metamorphosed andesite thought to overlie a concealed pluton at no great depth (Miller and Ferrians, 1968, p. 6).

Chemical analyses were obtained on two typical granodiorites (table 12; nos. 17 and 18), on two of the satellitic dacitic dikes (nos. 21 and 22), and on two quartz monzonites with more variable composition (nos. 19 and 20). The granodiorites and dacites have very similar compositions except for a higher H_2O content in the dacite. Compared with Nockolds (1954) average granodiorite and with the Zane Hills rocks, the granodiorite in this body has higher CaO and much lower K_2O. Sample 19 is from a slightly contaminated rock near the contact and has lower SiO_2. Sample 20 is from a group of small pinnacles protruding above the general surface in the southern part of the pluton and is thought to be a late felsic member of the pluton.

PETROGRAPHIC AND CHEMICAL SUMMARY OF THE PLUTONIC ROCKS

The mid-Cretaceous plutonic rocks show a wide range in composition both in the suite as a whole and in individual plutons. The most common rock type is saturated syenite and monzonite but oversaturated quartz monzonite makes up a large part of the exposed plutonic rocks and the suite includes potassic subsilicic rocks.

The compositional range is shown in figure 29 by a plot of the modal quartz, K-feldspar, and plagioclase of the granitic rocks of the suite. Monzonites, syenites, syenodiorites, quartz monzonites, and granodiorites are all present but low quartz (<10 percent) and K-feldspar rich rocks (>35 percent) are the most abundant. It should be remembered that the sampling density is not uniform for the various plutons in the suite and this bias is reflected in the distribution; however, the plot shown here is thought to be representative.

A plot of the normative salic components (fig. 30) for the granitic rocks shows a distribution and concentration similar to the modal plot although not extending as far toward the orthoclase apex. Again, the majority of rocks shows a low quartz content and a relatively high orthoclase content.

The range of composition for the entire suite including both oversaturated and undersaturated rocks is shown in figure 31 where SiO_2 is plotted against the Thornton-Tuttle (1960)

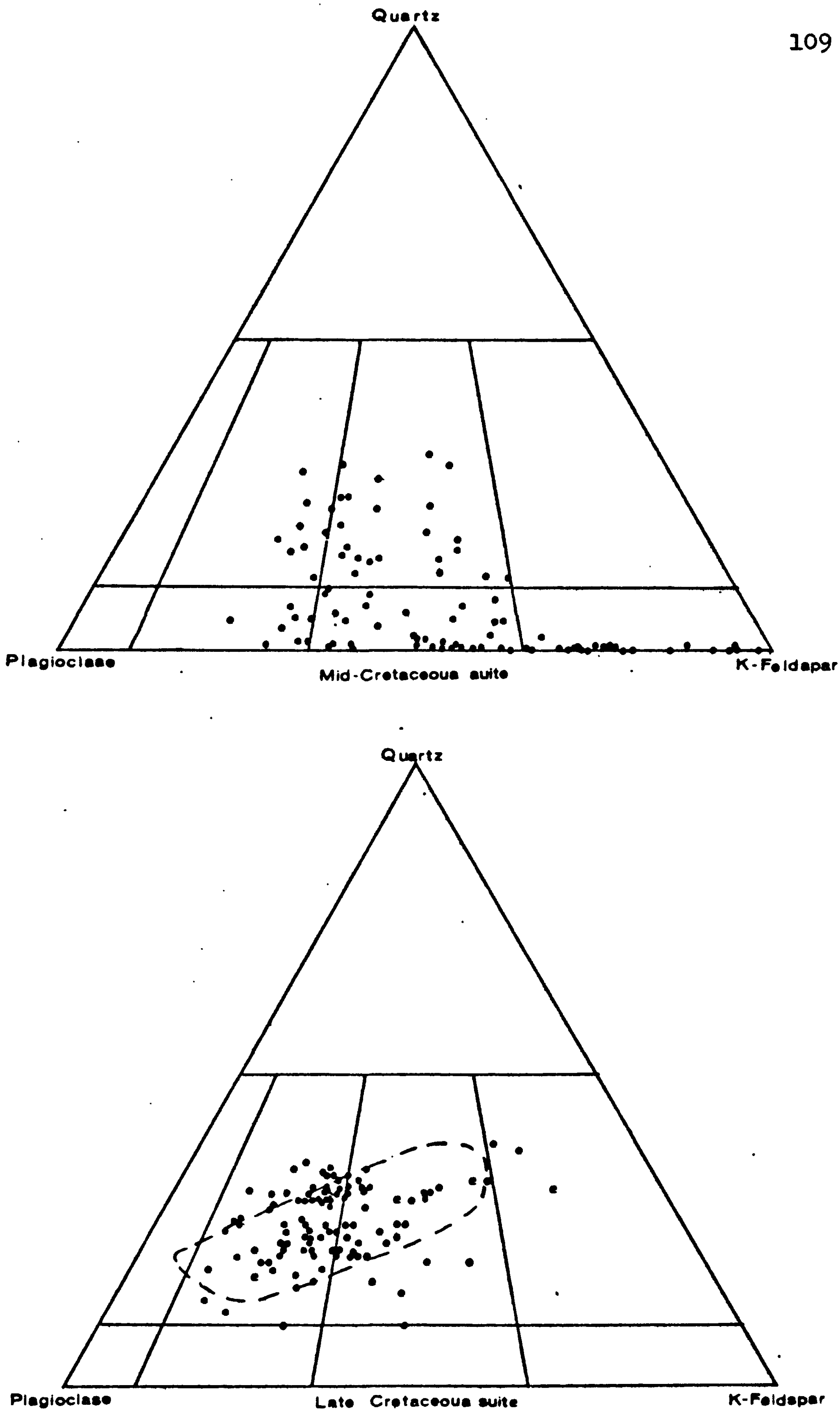


Figure 29. Modal analyses of the granitic rocks of the mid-Cretaceous suite and of the Zane Hills and Wheeler Creek plutons of the Late Cretaceous suite; dashed line represents range of modal analyses from the east-central Sierra Nevada batholith (from Bateman and others, 1963).

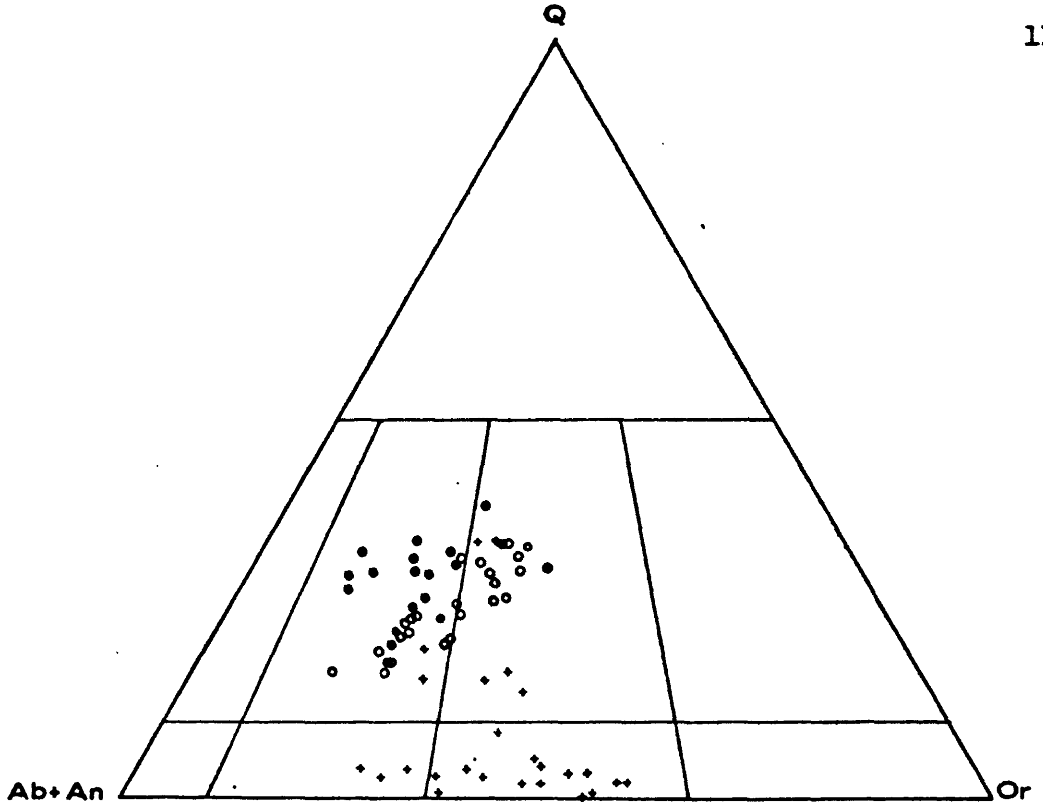


Figure 30. Comparison of the normative trends of the granitic rocks of west-central Alaska (•, Late Cretaceous suite; +, mid-Cretaceous suite) with granitic rocks from the east-central Sierra Nevada batholith (o; Bateman and others, 1963).

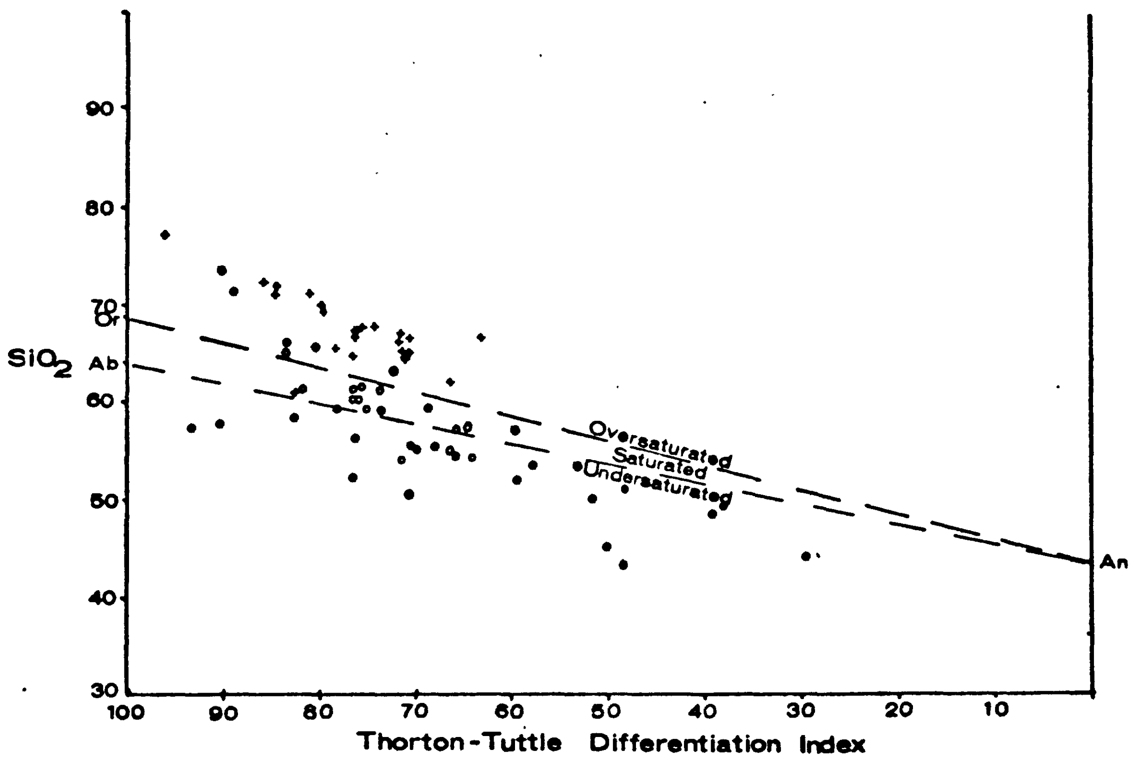


Figure 31. SiO_2 plotted against Thorton-Tuttle differentiation index for the plutonic rocks of west-central Alaska: +, Late Cretaceous suite; o, mid-Cretaceous granitic rocks; •, mid-Cretaceous alkaline rocks.

differentiation index for all analyzed samples in the suite. Most of the granitic rocks do indeed plot in the saturated part of the diagram and only a few plot in the undersaturated part.

The rocks of the suite range from leucocratic to mesocratic and the color index ranges from 6 to 45. The chief mafic minerals are hornblende and clinopyroxene; biotite is generally less common.

The fabric shows as much variability as the composition. Planar flow structures and porphyritic, trachytoid, and gneissoid textures are common, particularly in the western plutons and in the alkaline rocks, and the grain size ranges from fine to coarse.

The Late Cretaceous suite is much more homogeneous in both composition and texture than the mid-Cretaceous suite. Individual plutons show some compositional zoning but the range is not great. Granodiorite and quartz monzonite are the chief rock types but alaskite, monzonite, and hybrid diorite occur locally. Quartz diorite and mafic end members commonly found in other calc-alkaline suites are not present.

A plot of the modal quartz, K-feldspar, and plagioclase is shown in figure 29 and shows the abundance of granodiorite and quartz monzonite. The modal composition of the granodiorite and quartz monzonite in the two largest plutons of the suite, the Zane Hills and Wheeler Creek plutons are compared with another calc-alkaline suite, the east-central Sierran Nevada batholith (Bateman and others, 1963). The two suites show similar trends and cover much the same field.

A plot of the normative salic components (fig. 30) shows the analyzed specimens to be mostly granodiorite; compared to the east-central Sierra Nevada rocks, they have somewhat more quartz and less orthoclase but the trends are similar. An Alk-F-M plot (fig. 32) of the plutonic rocks of the two areas shows they have similar trends but the Alaskan rocks show less iron than the Sierran rocks and Nockolds (1954) average calc-alkaline suite.

The plutonic rocks of the Late Cretaceous suite are typically leucocratic with a color index generally under 10. Biotite and hornblende are the chief mafic minerals; pyroxene is rare except in the monzonite and hybrid diorite of the Zane Hills pluton.

The Late Cretaceous plutonic rocks are typically structureless; only the monzonite of the Zane Hills pluton shows an oriented fabric ranging from a planar flow structure to gneissoid. Most of the plutonic rocks are medium-grained, massive, and generally hypidiomorphic granular with the exception of the quartz monzonite of the Wheeler Creek pluton which is characteristically porphyritic.

Both suites of plutons characteristically show sharp contacts with the country rock and have satellitic dikes and sills extending out into it. These country rocks, chiefly Lower Cretaceous andesitic volcanics, are moderately to strongly deformed but have not been regionally metamorphosed. The plutons appear to be magmatic epizonal bodies which in at least two places intruded hypabyssal rocks similar in composition and only slightly older.

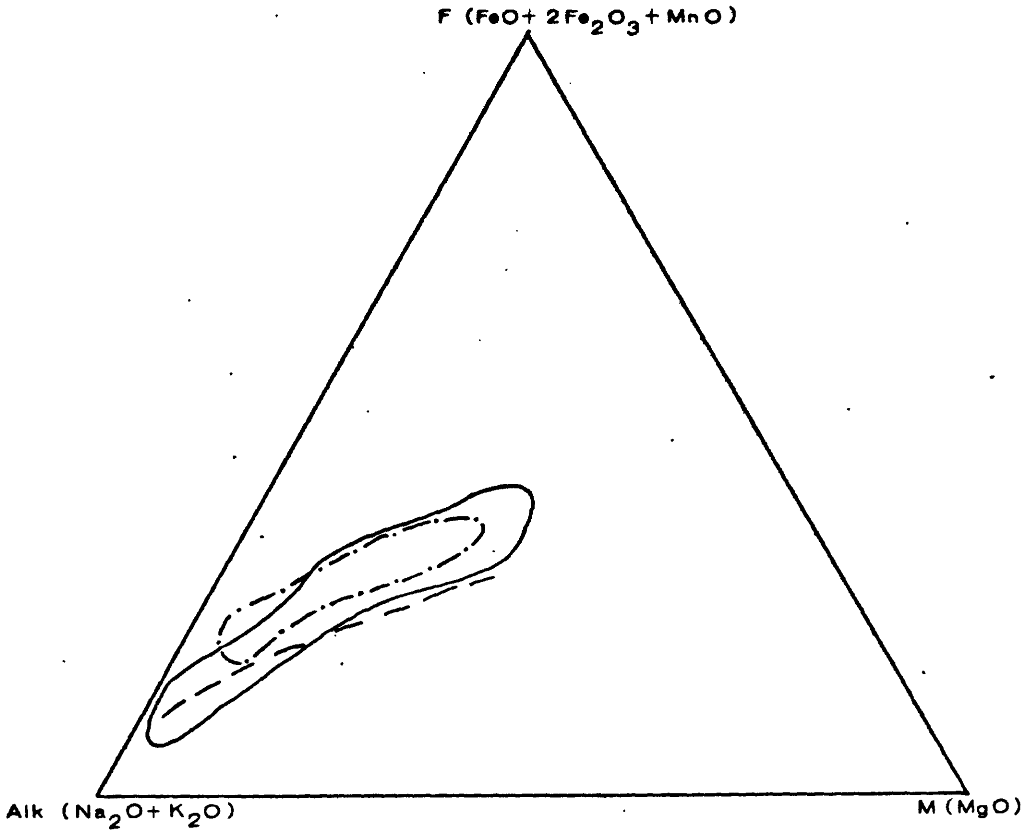


Figure 32. Comparison of the chemical trends of the Late Cretaceous suite (dashed line) with calc-alkaline granitic rocks of the eastern Sierra Nevada batholith (Ross, 1969; solid line) and with the average calc-alkaline suite of Nockolds (1954; dot-dash).

PETROGENESIS AND CONCLUSIONS

Any hypothesis concerning the petrogenesis of the Hogatza plutonic belt must address itself not only to problems concerning the origin of granitic rocks in general but also to these two primary questions: (1) What is the origin of the potassic subsilicic rocks of the mid-Cretaceous suite, particularly if juvenile sialic material is not present over much of the area, and (2) why was the potassic enrichment confined to the western part of the belt and absent in the younger, calc-alkaline rocks to the east.

Current hypotheses for the formation of granitic rocks of the composition of the Late Cretaceous suite and the quartz monzonite of the mid-Cretaceous suite have been grouped by Piwinskii and Wyllie (1968) as follows: (1) differentiation of a parent, more mafic magma by fractional crystallization, (2) anatexis of crustal rocks, (3) contamination of magma formed by (1) or (2) by assimilation of country rock, and (4) hybridization of granitic and mafic magmas. While recognizing the reconnaissance nature of much of the present study, some speculations on the origin of the plutonic rocks of west-central Alaska can be made in respect to the above hypotheses.

Derivation of the magma by differentiation of a basaltic or andesitic parent magma is a possibility, but the lack of mafic comagmatic rocks in the suite makes this mode of origin seem unlikely. The amount of quartz-rich granitic rock generated was considerable (over 500 square miles in the Late Cretaceous suite alone is now exposed) and volume considerations would seem to require more mafic rocks.

Many workers have proposed an anatectic origin for granitic rocks based both on field studies (Bateman and Eaton, 1967) and experimental work (Tuttle and Bowen, 1958). Recent work by Piwinskii and Wyllie (1968, p. 230), however, suggests that although a granitic liquid can be readily formed by anatexis at moderate temperatures, the formation of granodioritic magma would require rather high temperatures, on the order of 900° C, or the magmas consisted of eutectic-like granite liquids with suspended mafic crystals. The high temperature would require an additional heat source to supplement radioactive heat generation in a volcanic pile and heat conduction from the mantle and Piwinskii and Wyllie (1968) have suggested this heat may be provided by emplacement into the lower crust of gabbroic magma from the mantle. In this regard, several investigations of strontium and lead isotope content (Hurley and others, 1965; Doe, 1967) in granitic rocks have suggested that mantle material has played a role in their origin.

An anatectic origin by melting at the base of the andesitic volcanic pile would seem to be a likely possibility in west-central Alaska. The total thickness of this widespread volcanic assemblage is not known but Patton (1970b) states that at least 5,000 feet are exposed on the Koyukuk River near Hughes and the total thickness may be several times that figure. The magma formed by anatexis at the base of this volcanic assemblage may have been mixed with gabbroic magma as suggested by Piwinskii and Wyllie (1968) and the resulting granodiorite and quartz monzonite magma then emplaced as separate plutons at higher levels in the crust. Contamination of wall rock material appears to have taken place in many of the plutons, particularly in the Late Cretaceous suite. However, its effect on the overall composition appears to have been relatively slight.

The mid-Cretaceous suite was obviously affected by other processes which resulted in the K-enrichment so noticeable in modal and normative trends. In the Selawik Hills pluton, for example, obvious effects of K-metasomatism can be observed in the north-central part of the pluton. The apparent igneous history of the pluton is interpreted as the intrusion of a rather low silica (60 to 66 percent) quartz monzonite into Lower Cretaceous andesitic volcanic rocks. This magma, already enriched somewhat in K_2O, engulfed large amounts of andesite country rock along its northern margin resulting in contamination of the magma. The still viscous magma was subjected to K-metasomatism and the resulting hybrid syenite, characterized by large K-feldspar phenocrysts and a gneissic to trachytoid texture, now forms the north-central part of the pluton. The small bodies of nepheline syenite in the hybrid syenite together with the occurrence of the ultrapotassic complexes in the Kobuk-Selawik Lowlands suggests the K-metasomatism is related to the alkaline magmatism.

The western Alaska alkaline rocks are potassic, as has been documented here. Potash is consistently high and generally greater than soda by a factor of two or more. Although these rocks range from melanocratic to leucocratic varieties, relatively mesocratic rocks such as malignite are among the most abundant rock types and appear to be the earliest variety emplaced.

Such potassic provinces are relatively rare in the igneous record--the classic domestic localities are the Leucite Hills in Wyoming, the Highwood Mountains of Montana, and the Navajo area in northeastern Arizona. Foreign localities include the Bufumbira area of eastern Africa which includes the Birunga and Toro-Ankole volcanic fields, the West Kimberly region of Australia, and the Italian Roman province. Most of these provinces are composed chiefly of extrusive and hypabyssal rocks and all are confined to continental areas with a considerable thickness of sialic crust.

Hypotheses involving the origin of potassium-rich basic magmas have been summarized by Turner and Verhoogen (1960) and fall into three groups: (1) the partial melting or resorption of biotite, which may be concentrated by fractionation in a liquid or as a residue from anatexis, (2) assimilation by reaction of basic or carbonatite magma with crustal material, and (3) those that consider magmatic fractionation.

Turner and Verhoogen themselves favor a hypothesis by which alkaline olivine basalt or nepheline-basalt magmas are involved in an assimilation reaction with granitic rocks of the continental basement resulting in potash-rich magma. However, an important fact to remember is that, as Bell and Powell (1969) point out, potassic rocks are the most potassium-rich of any known silicate rock and their potassium contents therefore cannot be explained by a simple mixing of two common materials.

The hypotheses listed by Turner and Verhoogen have been discussed in the light of more recent work on Sr isotopic composition of the East Africa potassic rocks (Bell and Powell, 1969) and on the chemical composition of the volcanic rocks of the Leucite Hills in Wyoming (Carmichael, 1967).

Bell and Powell showed the Sr^{87}/Sr^{86} ratios of the Birunga and Toro-Ankole rocks have a positive, linear correlation with the Rb/Sr ratio and negative correlations with Sr, Nb, and Zr. They conclude that the hypotheses that would be most in keeping with the data are (1) the assimilation of sialic material by either a nephelinite magma or a carbonatite magma, or (2) the partial melting of an old potassic substratum.

Hurley and others (1966), however, in an earlier study of Sr isotopes and the concentration of Sr and other trace elements in the Roman province, concluded that continental potassic volcanic rocks could not have derived their high Sr content from carbonatite or "normal" basalt or from limestone syntexis. The Sr isotopes suggest the potash-rich magma was derived from remelting of ancient sialic rocks.

The lack of agreement in the Sr isotopic and abundance studies of the two provinces was noted by Bell and Powell (p. 559) who stated that "it is not clear whether their [Hurley and others] results indicate that the rocks of the Roman province had a different origin from those of East Africa, or whether their samples were not sufficiently diverse in composition to permit a proper comparison."

At any rate, the two studies both favor the concept of sialic involvement in the origin of potassic rocks although the possibility of more than one origin would seem to be left open.

Carmichael's study of the Leucite Hills province resulted in a different conclusion in regard to petrogenesis. Carmichael studied the three principal rock types of the Leucite Hills, the undersaturated madupite and the oversaturated wyomingite and orendite, with the electron microprobe. Based on the results of mineral and rock analyses, together with melting experiments, he concluded that these potassic rocks have a melting range comparable to magnesian basalt and that a crustal origin was precluded. He found little evidence that sialic contamination affected the composition of the oversaturated rocks but the madupite could have been formed by crystal fractionation at high pressure of a liquid derived from partial fusion of garnet-peridotite.

In attempting to apply these various hypotheses and data to the potassic rocks of western Alaska province, the possible lack of juvenile sialic material must be kept in mind. Many of the above hypotheses depend on the contamination or refusion of sialic crust to attain the necessary abundance patterns and isotopic composition. The lack of such material necessitates the finding of other possible sources of potassium.

The country rock for much of the alkaline province is andesitic volcanic rock; however, the occurrence of alkaline rocks of similar composition in older metamorphic and sedimentary rocks in the southern Darby Mountains and at Cape Dezhnev suggests that the andesitic rocks had nothing to do with the formation of potash-rich alkaline magma.

It therefore appears likely that potash-rich magma in western Alaska was formed in the mantle. Most of the potassic provinces described above occur in continental regions; however, as Carmichael (1967, p. 60) has pointed out, the fact that potassic lavas have not been found in the oceanic islands does not necessarily imply a genetic relationship to sialic material since these are extremely scarce rocks. Also, in this regard, recent work by McBirney and Aoki (1968) on the igneous rocks of Tahiti has shown them to be the most strongly alkaline rocks in the Pacific and, while not potassic in the sense that potash is greater than soda, "the alkalis are more nearly equal than in most other oceanic islands" (p. 544).

A mantle origin for the potassic mafic rocks has been suggested by several other workers. O'Hara and Yoder (1967) believe that fractional crystallization of the liquid produced by partial melting of garnet peridotite produces eclogite accumulates and silica-poor alkaline residual liquids which have geochemical similarities to kimberlite or to potassic mafic rocks. Kushiro and others (1967) have suggested that phlogopite could be the stable potassium-bearing mineral in the upper mantle to depths of 150-200 km. If partial melting of the phlogopite-bearing peridotite took place, phlogopite would be involved and the resulting magma would be enriched in potassium.

The potash content of material thought to form the primary undifferentiated mantle, namely pyrolite, is low indeed, something like 0.22 percent according to Ringwood and others (1964). The relatively high potash content, 1.17 percent (Nockolds, 1954) of kimberlite suggests some potassium enrichment does occur in the mantle since kimberlite is thought to be generated at such depths (O'Hara and Mercy, 1963). Bell and Powell (1969, p. 563) quote P. G. Harris as favoring a hypothesis of partial melting of old kimberlitic material at depth. This resembles the proposal of Waters (1955) that the biotite pyroxenites commonly found in potassic provinces are xenoliths of ultramafites altered during successive episodes of anatexis and the potassic rocks were formed by partial melting of this material. Biotite pyroxenite has been found locally at several of the complexes in western Alaska; the poor exposures preclude a determination of its setting but its occurrence in relatively small areas suggests it could be xenolithic.

Implying that these rocks are derived from magma which originated in the mantle means that either the potassium content of the mantle varies considerably and has local concentrations (Carmichael, 1967, p. 62) or that the potassium concentration is uniform but for some reason, possibly involving zone melting of phlogopite-bearing peridotites (Kushiro, 1968), potassium was concentrated in magma generated in this region. Whatever the ultimate source of the potassium, the volume of potassium-enriched rock is of regional extent when the amount of syenite, monzonite, and alkaline subsilicic rocks of the mid-Cretaceous suite is considered.

A possible hypothesis for the petrogenesis of the mid-Cretaceous suite of plutonic rocks is that potassium-rich magma was generated, probably in the mantle, along a zone of structural weakness near the boundary between two major geologic provinces in western Alaska. This magma formed a belt of strongly potassic subsilicic complexes and also resulted in the potassium-enrichment, by metasomatism and(or) mixing of magmas, granitic magmas which were forming by anatexis of andesitic material.

In Late Cretaceous time, the loci of plutonic magmatism in the Mesozoic volcanogenic province of west-central Alaska shifted to the east. The magma formed in this part of the Hogatza plutonic belt resulted in quartzose granodiorite and quartz monzonite similar to many other plutonic provinces in the North America Cordillera. This suite is generally homogeneous in composition.

Individual plutons are zoned but the variations in composition can be related to contamination of andesitic wall rock along the roof zone of the pluton or to local metasomatism. The lack of potassium enrichment, other than as a local feature in the Zane Hills, indicates that either (1) potassium was not concentrated in the mantle in this region, or (2) that the tectonic events that controlled and perhaps helped generate the potassic magmas to the west did not take place here, or (3) a combination of (1) and (2).

REFERENCES CITED

Backlund, H. G., 1932, On the mode of intrusion of deep-seated alkaline bodies: Bull. Geol. Inst. Univ. Uppsala, v. 24, p. 1-24.

Bailey, D. K., 1961, The mid-Zambezi-Luangwa rift and related car bonatite activity: Geol. Mag., v. 98, p. 277-284.

________, 1964, Crustal warping--a possible tectonic control of alkaline magmatism: Jour. Geophys. Res., v. 69, p. 1103-1111.

Bailey, E. H., and Steven, R. E., 1960, Selective staining of K-feldspar and plagioclase on rock slabs and thin-sections: Am. Mineralogist, v. 45, nos. 9-10, p. 1020-1025.

Barker, D. S., 1969, North American feldspathoidal rocks in space and time: Geol. Soc. America Bull., v. 80, p. 2369-2372.

Bateman, P. C., Clark, L., Huber, N. F., Moore, J. G., and Rinehart, C. D., 1963, The Sierra Nevada batholith, a synthesis of recent work across the central part: U. S. Geol. Survey Prof. Paper 414-D, p. D1-D46.

Bateman, P. C., and Eaton, J. P., 1967, Sierra Nevada batholith: Science, v. 158, no. 3807, p. 1407-1417.

Bell, Keith, and Powell, J. L., 1969, Strontium isotope studies of alkalic rocks: The potassium-rich lavas of the Birunga and Toro-Ankole Regions, East and Central Equatorial Africa: Jour. Petrology, v. 10, Part 3, p. 536-572.

Bowen, N. L., 1928, The evolution of the igneous rocks: Princeton Univ. Press, Reprint by Dover Publications, Inc., 1956, 332 p.

Buie, B. F., 1941, Igneous rocks of the Highwood Mountains; part III, Dikes and related intrusives: Geol. Soc. America Bull., v. 52, p. 1753-1808.

Burgess, C. H., 1941, Igneous rocks of the Highwood Mountains; part IV, the stocks: Geol. Soc. America, v. 52, p. 1809-1828.

Burley, B. J., Freeman, E. B., and Shaw, D. M., 1961, Studies on scapolite: Canadian Mineral, v. 6, p. 670.

Buddington, A. F., 1959, Granite emplacement with special reference to North America: Geol. Soc. America Bull., v. 70, p. 671-747.

Carmichael, Ian S. E., 1967, The mineralogy and petrology of the volcanic rocks from the Leucite Hills, Wyoming: Contr. Mineral. and Petrol., v. 15, p. 24-66.

Coulter, H. W., Hopkins, D. M., Karlstrom, T. N. V., Pewe, T. L., Wahrhaftig, Clyde, and Williams, J. R., 1965, Map showing extent of glaciations in Alaska: U. S. Geol. Survey Misc. Geol. Inv. Map I-415, Scale 1:2,500,000.

Deer, W. A., Howie, R. A., and Zussman, J., 1963, Rock-forming minerals, vol. 4 (framework silicates): John Wiley and Sons, Inc., 435 p.

Doe, B. R., 1967, The bearing of lead isotopes on the source of granitic magma: Jour. Petrology, v. 8, p. 51-83.

Eakin, H. M., 1916, The Yukon-Koyukuk region, Alaska: U. S. Geol. Survey Bull. 631, 88 p.

Elliott, R. L., and Miller, T. P., 1969, Results of stream sediment sampling in the western Candle and southern Selawik quadrangles, Alaska: U. S. Geol. Surv. Open-file report, 61 p.

Erickson, R. L., and Blade, L. V., 1963, Geochemistry and petrology of the alkalic igneous complex at Magnet Cove, Arkansas: U. S. Geol. Surv. Prof. Paper 425, 95 p.

Fudali, R. F., 1963, Experimental studies bearing on the origin of pseudoleucite and associated problems of alkalic rock systems, Bull. Geol. Soc. America, 74, p. 1101-1126.

Gault, H. R., Killeen, P. L., West, W. S., and others, 1953, Reconnaissance for radioactive deposits in the northeastern part of the Seward Peninsula, Alaska, 1945-47 and 1951: U. S. Geol. Survey Circ. 250, 31 p.

Gerasimovskii, V. I., 1966, Geochemical features of agpaitic nepheline-syenites, p. 104-118 in Vinogradov, A. P., Editor, Chemistry of the earth's crust: Izd. Akad. Nauk SSSR, Moscow, v. 1, 458 p.

Green, Jack, 1959, Geochemical table of the elements for 1959: Geol. Soc. America Bull., v. 70, no. 9, p. 1127-1185.

Hamilton, D. L., and MacKenzie, W. S., 1960, Nepheline solid solution in the system $NaAlSiO_4$-$KAlSiO_4$-SiO_2: Jour. Petrol., v. 1, p. 56-72.

Harrington, G. L., 1919, Mineral resources of Alaska, report on progress of investigations in 1917: U. S. Geol. Survey Bull. 692, p. 353-408.

Heinrich, E. Wm., 1966, The geology of carbonatites: Rand McNally and Company, Chicago, 555 p.

Horne, J., and Teall, J. J. H., 1892, On borolanite, an igneous rock intrusive in the Cambrian limestone of Assyut, Sutherlandshire, Trans. Roy. Soc. Edin., v. 37, p. 163-177.

Hurley, P. M., Bateman, P. C., Fairbairn, H., and Pinson, W., 1965, Investigation of initial Sr^{87}/Sr^{86} ratios in the Sierra Nevada plutonic province: Geol. Soc. America Bull., v. 76, p. 165-174.

Hurley, P. M., Fairbairn, H. W., and Pinson, W. H., 1966, Rb-Sr Isotopic evidence in the origin of potash-rich lavas of western Italy: Earth and Plan. Sci. Letters 5, p. 301-306.

Johannsen, A., 1939, A descriptive petrography of the igneous rocks: Chicago, Univ. Chicago Press, v. 1, 318 p.

King, B. C., and Sutherland, D. S., 1960, Alkaline rocks of eastern and southern Africa, Part I: Distribution, ages, and structures: Sci. Progr., v. 48, p. 298-321.

Kumarapeli, P. S., 1970, Monteregian alkalic magmatism and the St. Lawrence rift system in space and time: Canadian Mineral., v. 10, part 3, p. 421-431.

Kushiro, I., 1968, Compositions of magmas formed by partial zone melting of the earth's upper mantle: Jour. Geophy. Res., v. 73, no. 2, p. 619-634.

Kushiro, I., Syono, Y., and Akimoto, S., 1967, Stability of phlogopite at high pressures and possible presence of phlogopite in the earth's upper mantle: Earth and Plant. Sci. Lett., v. 3, p. 197-203.

Larsen, E. S., 1941, Igneous rocks of the Highwood Mountains, Montana; Part III, the extrusive rocks: Geol. Soc. America Bull., v. 52, p. 1733-1752.

Lugov, S. F., 1959, Vozrast granitoidov Chukotki po dannym argonovogo metoda i geologicheskii nablyudonii, Sovetskaya Geologiya 5, p. 142-148.

Luth, W. C., 1967, Studies in the system $KAlSiO_4$-Mg_2SiO_4-SiO_2-H_2O: I, Inferred phase relations and petrologic applications: Jour. Petrology, v. 8, pt. 3, p. 372-416.

McBirney, A. R., and Aoki, K., 1969, Petrology of the island of Tahiti, p. 523-556, in Coats, R. R., May, R. L., and Anderson, C. A., Ed., Studies in volcanology: Geol. Soc. Am. Mem. 116, 678 p.

Miller, T. P., 1969, Results of stream sediment sampling in the northern Melozitna, Hughes, and southern Shungnak quadrangles, west-central Alaska: U. S. Geol. Survey Open-file report, 53 p.

Miller, T. P., and Elliott, R. L., 1969, Metalliferous deposits near Granite Mountain, eastern Seward Peninsula, Alaska: U. S. Geol. Survey Circ. 614, 19 p.

Miller, T. P., and Ferrians, O. J., Jr., 1968, Suggested areas for prospecting in the central Koyukuk River region, Alaska: U. S. Geol. Survey Circ. 570, 12 p.

Miller, T. P., Patton, W. W., Jr., and Lanphere, M. A., 1966, Preliminary report on a plutonic belt in west-central Alaska, in Geological Survey research 1966: U. S. Geol. Survey Prof. Paper 550-D, p. D158-D162.

Miser, H. D., 1934, Carboniferous rocks of Oauchita Mountains: Am. Assoc. Petroleum Geologists Bull., v. 18, no. 8, p. 971-1009.

Moffit, F. H., 1905, The Fairhaven gold placers, Seward Peninsula, Alaska: U. S. Geol. Survey Bull. 247, 85 p.

Nockolds, S. R., 1954, Average chemical compositions of some igneous rocks: Geol. Soc. America Bull., v. 65, no. 10, p. 1007-1032.

O'Hara, M. J., and Mercy, E. L. P., 1963, Petrology and petrogenesis of some garnetiferous peridotite: Trans. Roy. Soc. Edin., v. 65, p. 251-314.

O'Hara, M. J., and Yoder, H. S., Jr., 1967, Formation and fractionation of basic magmas at high pressures: Scot. Jour. Geol., v. 3, pt. 1, p. 67-117.

Parker, R. L., and Fleischer, M., 1968, Geochemistry of niobium and tantalum: U. S. Geol. Surv. Prof. Paper 612, 43 p.

Parsons, G. E., 1961, Niobium-bearing complexes east of Lake Superior: Ontario Dept. Mines, Geol. Report No. 3, 73 p.

Patton, W. W., Jr., 1966, Regional geology of the Kateel River quadrangle, Alaska: U. S. Geol. Survey Misc. Geol. Inv. Map I-437.

________, 1967, Regional geologic map of the Candle quadrangle, Alaska: U. S. Geol. Survey Misc. Geol. Inv. Map I-492, scale 1:250,000.

________, 1970a, Discussion, in Tailleur, I. L., and Brosgé, W. P., Tectonic history of northern Alaska: Proceedings of the geological seminar on the north slope of Alaska, Pacific Sect., Am. Assoc. Petroleum Geologists, p. E20.

________, 1970b, Petroleum possibilities of the Yukon-Koyukuk province, Alaska: U. S. Geol. Survey Open-File report, p. 13.

Patton, W. W., Jr., and Miller, T. P., 1966, Regional geologic map of the Hughes quadrangle, Alaska: U. S. Geol. Survey Misc. Geol. Inv. Map I-459, scale 1:250,000.

Patton, W. W., Jr., and Miller, T. P., 1968, Regional geologic map of the Selawik and southeastern Baird Mountain quadrangles, Alaska: U. S. Geol. Survey Misc. Geol. Inv. Map I-530, scale 1:250,000.

Patton, W. W., Jr., and Miller, T. P., 1970, Preliminary geologic investigations in the Kanuti River region, Alaska: U. S. Geol. Survey Bull. 1312-J, 10 p.

Patton, W. W., Jr., Miller, T. P., and Tailleur, I. L., 1968, Regional geologic map of the Shungnak and southern part of the Ambler River quadrangles, Alaska: U. S. Geol. Survey Misc. Geol. Inv. Map I-554, scale 1:250,000.

Perchuk, L. L., 1965, Magmatic Replacement of carbonate bodies involving formation of nepheline syenites and other alkalic rocks, with example of Cape Dezhnev massif: Inter. Geol. Rev., v. 7, no. 2, p. 280-296.

Piwinskii, A. J., and Wyllie, P. J., 1968, Experimental studies of igneous rock series: A zoned pluton in the Wallowa batholith, Oregon: Jour. Geology, v. 76, p. 205-234.

Quinn, Alonzo, 1937, Petrology of the alkaline rocks at Red Hill, New Hampshire: Bull. Geol. Soc. America, v. 48, p. 373-402.

Ringwood, A. E., MacGregor, I. D., and Boyd, F. R., 1964, Petrologic constitution of the upper mantle: Carnegie Inst. Washington, Ann. Rept. Direct. Geophys. Lab, 1963-1964, p. 147-152.

Ross, D. C., 1969, Descriptive petrography of three large granitic bodies in the Inyo Mountains, California: U. S. Geol. Survey Prof. Paper 601, 47 p.

Rutland, R. W. R., 1965, Tectonic overpressures, in Pitcher, W. S., and Flinn, G. W., Editors, Controls of metamorphism, John Wiley & Sons, Inc., New York, 368 p.

Sahama, Th. G., 1953, Mineralogy and petrology of a lava flow from Mt. Nyiragongo, North Kivu, Belgian Congo, Amn. Acad. Sci. Fennicae, ser. A-III, no. 36, p. 1-20.

________, 1962, Perthite-like exsolution in the nepheline-kalsilite system: Norsk Geol. Tidssk., v. 42, pt. 2, p. 168-179.

Sainsbury, C. L., 1969, The A. J. Collier thrust belt of the Seward Peninsula: Geol. Soc. America Bull., v. 80, no. 12, p. 2595-2596.

Shand, S. J., 1939, Loch Borolan laccolith, northwest Scotland: Jour. Geology, v. 47, p. 408-420.

Shapiro, Leonard, and Brannock, W. W., 1956, Rapid analysis of silicate rocks: U. S. Geol. Survey Bull. 1036-C, p. 19-56.

Smith, F. G., 1963, Physical geochemistry: Addison-Wesley Publishing Co., Inc., Reading, Mass., 624 p.

Smith, P. S., 1913, The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, 160 p.

Smith, P. S., and Eakin, H. M., 1911, A geologic reconnaissance in southeastern Seward Peninsula and the Norton Bay-Nulato region, Alaska: U. S. Geol. Survey Bull. 449, 146 p.

Smith, W. C., A review of some problems of African carbonatites: Geol. Soc. London Quart. Jour., v. 112, p. 189-219.

Thornton, C. P., and Tuttle, O. F., 1960, Chemistry of igneous rocks--I, differentiation index: Am., Jour. Sci., v. 258, no. 9, p. 664-684.

Tilley, C. E., 1958a, Some new chemical data on assemblages of the Assynt alkali suites: Trans. Edin. Geol. Soc., v. 17, pt. 2, p. 156-164.

________, 1958b, Problems of alkali rock genesis: Quart. Jour. Geol. Soc. London, v. 106, p. 37-61.

Turner, F. J., and Verhoogen, J., 1960, Igneous and metamorphic petrology, 2nd Edition, McGraw-Hill, New York, 694 p.

Tuttle, O. F., and Bowen, N. L., 1958, Origin of granite in light of experimental studies in the system $NaAlSi_3O_8$-$KAlSi_3O_8$-SiO_2-H_2O: Geol. Soc. America Mem. 74, 153 p.

Vance, J. A., 1962, Zoning in igneous plagioclase--normal and oscillatory zoning: Am. Jour. Sci., v. 260, no. 10, p. 746-760.

Von Eckermann, H., 1948, The alkaline district of Alnö Islands; Sveriges Geologiska Undersokning, No. 36, Sweden, 176 p.

Wahrhaftig, Clyde, 1965, Physiographic divisions of Alaska: U. S. Geol. Survey Prof. Paper 482, 51 p.

Waters, A. C., 1955, Volcanic rocks and the tectonic cycle: Geol. Soc. America Spec. Paper 62, p. 703-722.

Watkinson, D. H., and Wyllie, P. J., 1969, Phase equilibrium studies bearing on the limestone-assimilation hypothesis, Geol. Soc. America Bull., v. 80, no. 8, p. 1565-1576.

Winkler, H. G. F., 1965, Petrogenesis of metamorphic rocks: Springer-Verlag, New York, Inc., 220 p.

Yoder, H. S., and Tilley, C. E., 1962, Origin of basalt magmas: an experimental study of natural and synthetic rock systems: Jour. Petrology, v. 3, p. 342-532.

Zhabin, A. G., 1959, On a new type of carbonatite manifestations associated with the alkalic complex of the Vishnevy-Ilmen Mountains in the Urals: Dokl. Akad. Nauk SSSR, Earth Sci. Sect., Earth Sc v. 128, p. 932-933, English Trans., 1960.

Zhidkov, A. Ya., 1963, The unique occurrence of ultra-potassium pseudoleucite syenites: Dokl. Akad. nauk SSSR, v. 152, no. 2, p. 414-417 (in Russian).

APPENDIX

APPENDIX

ANALYTICAL DATA FOR PREVIOUSLY UNPUBLISHED K/Ar AGES

Sample No.	Mineral	Percent K_2O	Ar^{40}_{rad} (moles/gm)	$Ar^{40}_{rad}/Ar^{40}_{total}$	Apparent Age (millions of years) $\pm 2\sigma$
4	Biotite	9.38) 9.32) 9.35	1.099×10^{-9}	.89	77.9 ± 2.3
8	Biotite	8.48	1.247×10^{-9}	.80	97 ± 3.0
12	Hornblende	1.62) 1.64) 1.63	2.637×10^{-10}	.95	106 ± 3.0

K^{40} decay constants: $\lambda_{\varepsilon} = 0.585 \times 10^{-10}$/year
$\lambda_{\beta} = 4.72 \times 10^{-10}$/year

Abundance ratio: $K^{40}/K = 1.19 \times 10^{-4}$ atom percent

Potassium analyses: Lois Schlocker

Argon analyses and age calculation:
Nos. 8 and 12, J. Von Essen
No. 4, J. Von Essen and Joan Engels

Location of: No. 4, Shungnak quadrangle, 66°18'N., 157°16'W.
No. 8, Selawik quadrangle, 66°02'N., 159°45'W.
No. 12, Candle quadrangle, 65°27'N., 161°13'W.

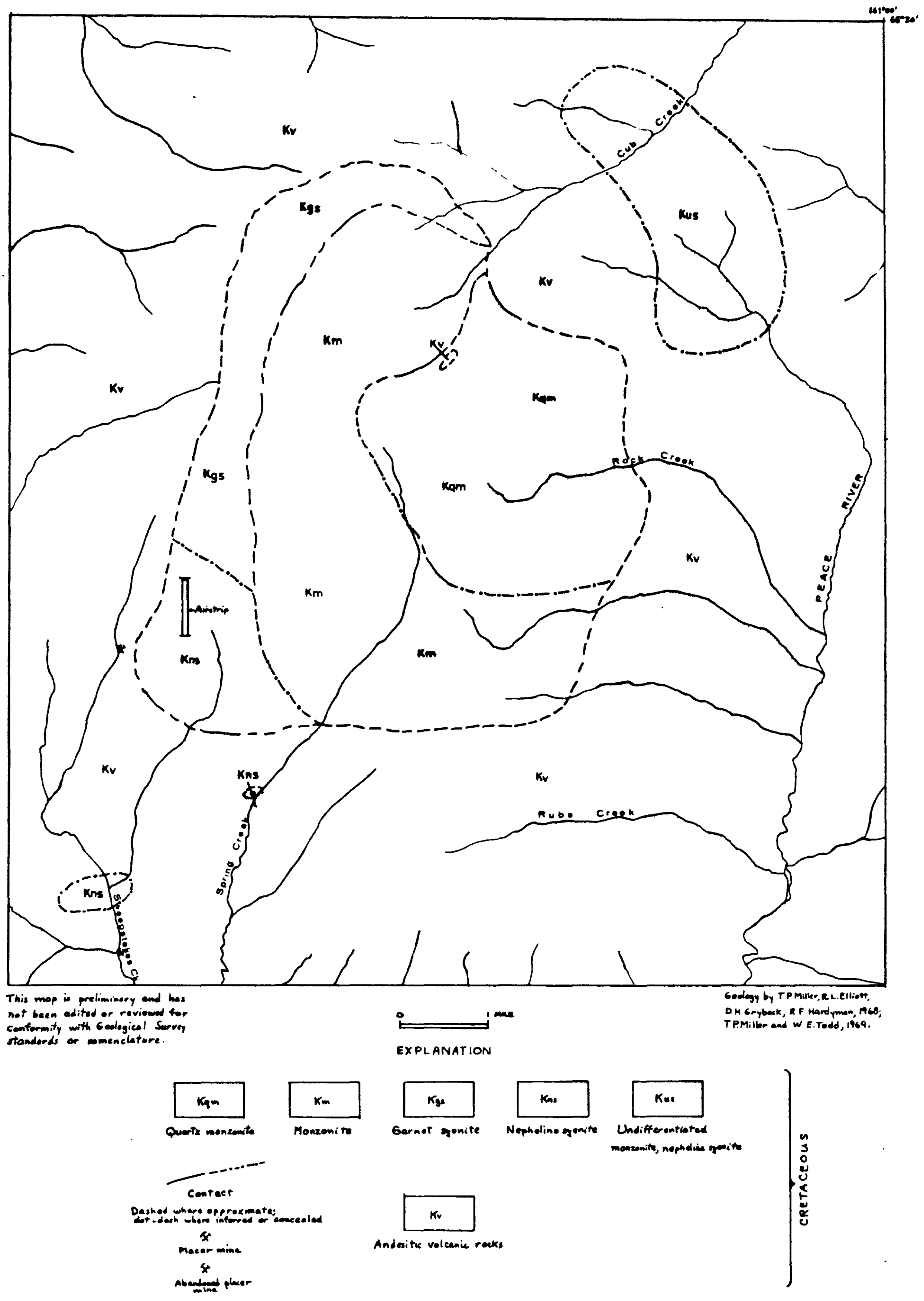
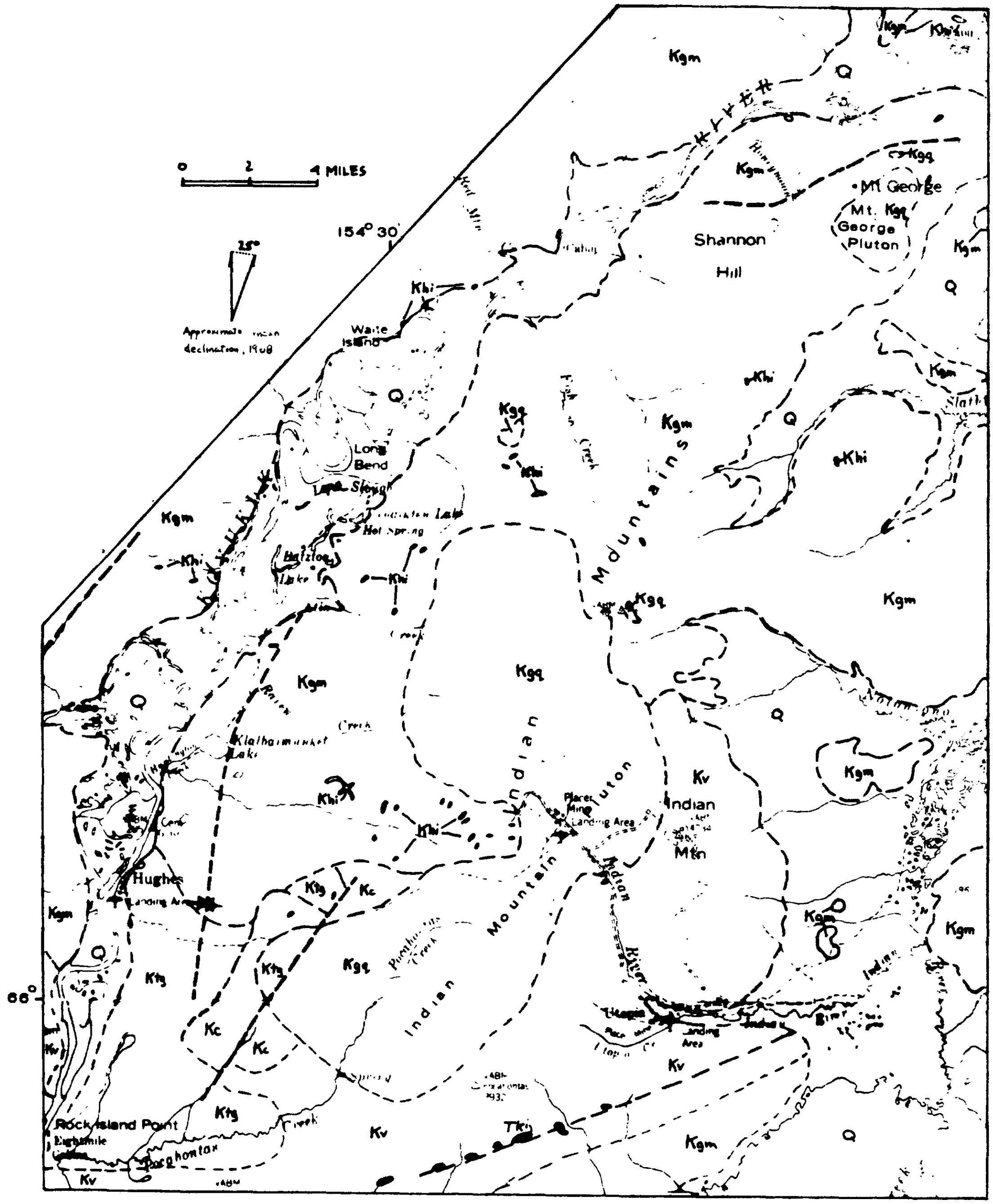


PLATE 4. Geologic map of the Granite Mountain Pluton.



Geology by W.W. Patton, Jr., and T.P. Miller, 1963-64; T.P. Miller and O.J. Ferrians, 1967.

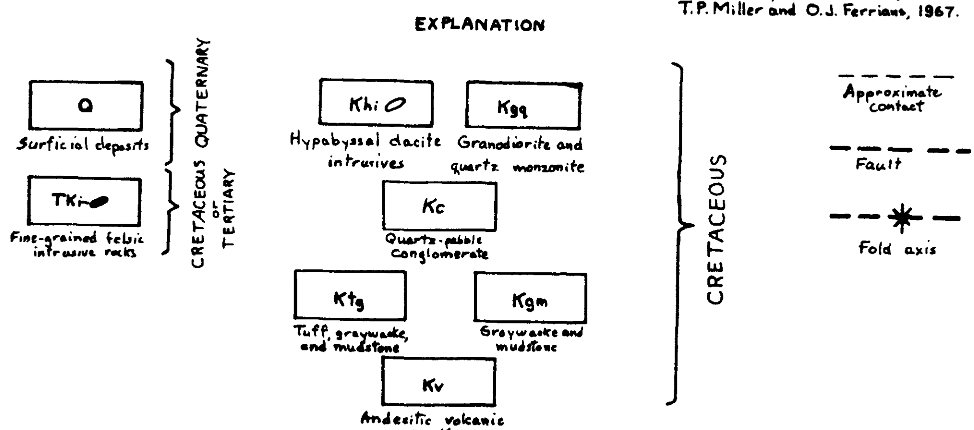


Plate 5. Geologic map of the Indian Mountain and Mt. George plutons, west-central Alaska.

This map is preliminary and has not been edited or reviewed for conformity with Geological Survey standards or nomenclature.