Geology and Ore Deposits of the Bokan Mountain Uranium-Thorium Area Southeastern Alaska

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GEOLOGICAL SURVEY BULLETIN 1154

Prepared on behalf of the United States Atomic Energy Commission and published with the permission of the Commission

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

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By E. M. MacKEVETT, Jr.

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GEOLOGY AND ORE DEPOSITS OF THE BOKAN MOUNTAIN URANIUM-THORIUM AREA, SOUTHEASTERN ALASKA

By E. M. MacKevett, Jr.

ABSTRACT

The Bokan Mountain uranium-thorium area includes about 71 square miles on the southern part of Prince of Wales Island and is largely underlain by plutonic rocks. Metasedimentary and metavolcanic rocks, probably of Devonian age, underlie about 5 percent of the area. The plutonic rocks, which are probably Cretaceous in age, range from pyroxenite to peralkaline granite and syenite, but they consist chiefly of diorite, quartz diorite, granodiorite, and quartz monzonite. The peralkaline granite, an uncommon rock type, forms a boss about 3 square miles in areal extent and contains abnormal quantities of many minor elements. Pegmatite and aplite dikes are common in and near the boss, but uncommon elsewhere. Fine-grained mafic dikes, chiefly of andesite and dacite, are abundant throughout most of the area, and diabase, rhyolite(?), and quartz latite(?) dikes are sparsely distributed. The rocks are cut by numerous faults and joints.

Most of the uranium-thorium deposits are genetically related to the peralkaline granite, and they occur either in the boss or within an altered (albitized) aureole, as much as 1½ miles wide, that surrounds the boss. The uranium-thorium deposits have four modes of occurrence: (1) concentrations of uranium-thorium-bearing accessory minerals in the peralkaline granite, a process which accounts for a small part of the Ross-Adams deposit; (2) veins or local replacements that contain uranium-thorium minerals of hydrothermal origin in or near fractures—this is the dominant occurrence of most of the Bokan Mountain area uranium-thorium deposits; (3) disseminated primary uranium-thorium minerals that are syngenetic in pegmatite and aplite dikes; and (4) uranium-thorium minerals of hydrothermal origin occupying interstices in clastic metasedimentary rocks—the only known occurrence of this type in the area is at the Cheri prospect.

Many radioactive minerals and a few minerals that contain rare earths and niobates were identified during the investigation.

The only uranium production from the area, which as of March 1959 constitutes the only uranium production from Alaska, consisted of about 15,000 tons of high-grade ore that was mined from the Ross-Adams deposit during the summer and fall of 1957. The Bokan Mountain area also contains copper and gold deposits, which are the sites of a few old mines and prospects, and iron deposits that have recently interested mining companies.

The minor elements of the rocks and ores were investigated by semiquantitative spectrographic analyses, and an endeavor was made to trace the distribution of 29 minor elements throughout the plutonic rock sequence.

INTRODUCTION

LOCATION AND ACCESSIBILITY

The Bokan Mountain uranium-thorium area is an irregular-shaped tract that includes about 71 square miles on the southeastern part of Prince of Wales Island, Alaska (fig. 1). It is between 4 and 5 miles wide and extends southeastward from the South Arm of Moira Sound to the vicinity of Stone Rock Bay. Except for a small part in the Prince Rupert D–6 quadrangle, the area is within the Dixon Entrance D–1 quadrangle—both quadrangles are editions of the 1:63,360 topographic series of the U.S. Geological Survey.

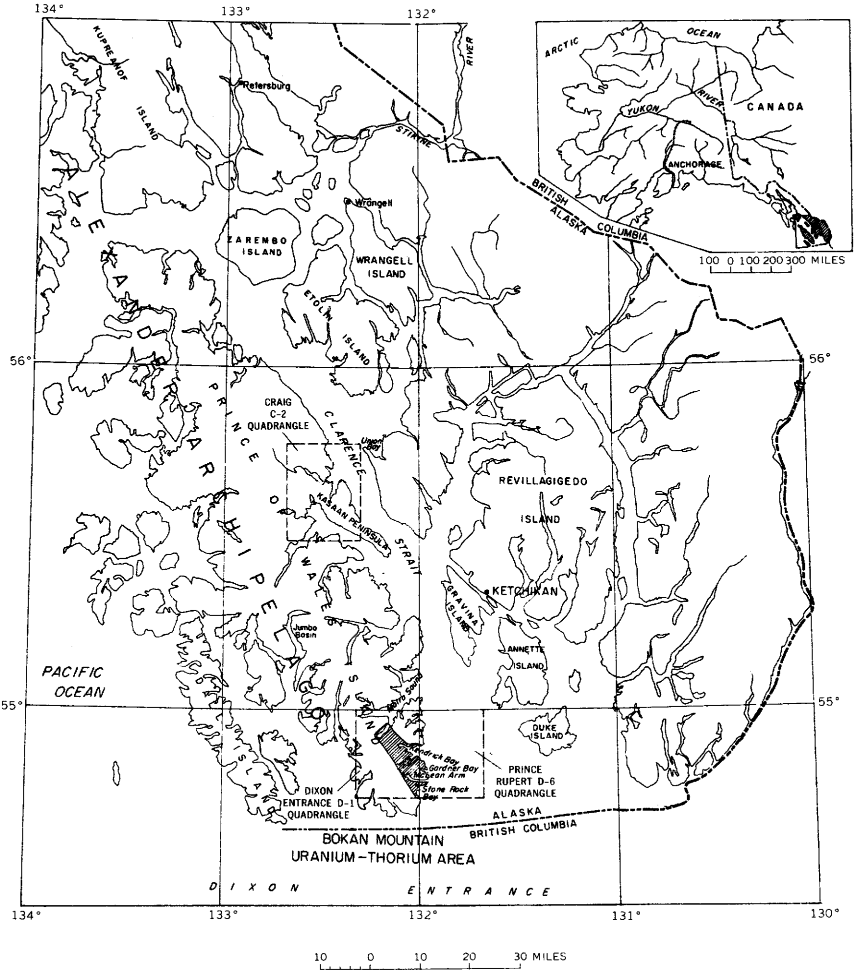

FIGURE 1.—Index map of part of southeastern Alaska showing the location of the Bokan Mountain uranium-thorium area.
]

The area is accessible by either floatplane or boat; both can be chartered in Ketchikan, a city located between 35 and 40 miles to the northeast. Travel within the area is chiefly by foot, a slow process that is generally impeded by muskeg, steep topography, dense brush, and slimy underfooting. Most of the trails are in poor condition. An unpaved haulage road about 1¾ miles long links the Ross-Adams mine with the dock on the West Arm of Kendrick Bay. Local access by boat or floatplane is facilitated by the many tidal embayments that penetrate Prince of Wales Island. Small floatplanes can also land on a few of the larger lakes.

GEOGRAPHY

The Bokan Mountain uranium-thorium area ranges from sea level to 2,713 feet in altitude and contains numerous fiordlike tidal embayments, islands, creeks, and many lakes and ponds, particularly in its muskeg-covered parts. To a large extent it is covered by a rain forest of Sitka spruce, cedar, and hemlock that is interspersed with swampy tracts of muskeg. Dense brush formed by blueberry or salmonberry bushes, or by devilsclub, is locally prevalent. Most of the higher terrains support scrubby trees and brush, but some of the higher peaks notably Bokan Mountain, and the summit areas of 2588 Peak west of the South Arm of Kendrick Bay, and 2713 Peak west of Gardner Bay, are characterized by bare rocky slopes.

The climate is relatively mild, and precipitation is heavy, chiefly between August and March. According to climatological data of the U.S. Department of Commerce (1958, p. 206, 208), based on records for at least 10 years, Ketchikan has an average total annual precipitation of 151.51 inches and an average mean annual temperature of 46.4°F, whereas the Annette Island airport, about 20 miles northeast of the mouth of Kendrick Bay, has an average total annual precipitation of 96.59 inches and an average annual temperature of 45.6°F. Strong southeast winds prevail during the frequent storms, and the accompanying waves erode the exposed shorelines adjacent to Clarence Strait. A tidal range in excess of 20 feet aids in developing a wide and bare littoral zone where rock exposures are excellent.

No permanent inhabitants live within the area. Commercial fishermen utilize some of the harbors as anchorages during the summer months, and trappers, prospectors, and hunters are infrequent land visitors. The Ross-Adams mine and most of the uranium-thorium prospects are in the northwestern part of the area near Bokan Mountain, but most of the known copper, gold, or iron deposits are near the southern limits of the area.

PURPOSE AND SCOPE OF WORK

The main objectives of the investigations on which this report is based were to determine the geologic settings, ore-controlling features, and economic potentials of the uranium-thorium deposits, and to contribute to an understanding of the regional geology by mapping an area that is geologically little known. The area contains some uncommon granitic rocks, and its largest known uranium deposit, the Ross-Adams, is an uncommon type.

The fieldwork consisted of making a geologic map of the Bokan Mountain uranium-thorium area on a 1 : 12,000 topographic base, using a planetable and alidade to make detailed geologic maps of the Ross-Adams deposit during several stages of its development, and making large-scale geologic maps of many of the uranium-thorium prospects and most of the accessible copper and gold mines and prospects using Brunton compass-tape methods. The gamma radioactivity was checked rather thoroughly at and near the known uranium-thorium deposits, but elsewhere it was determined at widely scattered localities during the course of mapping. Both Geiger and scintillation counters were used in the investigations for radioactivity. A total of about 7 months during the summers of 1956, 1957, and 1958 was spent in the field.

Laboratory investigation consisted mainly of petrographic studies and detailed mineralogic studies using immersion oils and X-ray diffraction methods.

This project is the basis for several reports by the writer including a description of the peralkaline granite (1957b), a preliminary geologic map of part of the area (1957c), descriptions of the Ross-Adams deposit (1958, 1959a), and a discussion of the modes of occurrence of the uranium-thorium minerals (1959b). Short summaries of various aspects of the Bokan Mountain uranium-thorium deposits by V. L. Freeman and J. J. Matzko (1956) and Freeman and (or) the writer (1956, 1957a, d) are incorporated in semiannual progress reports on geologic investigations of radioactive deposits published by the Technical Information Service Extension of the U.S. Atomic Energy Commission.

PREVIOUS WORK AND ACKNOWLEDGMENTS

The previous geologic work in the area includes reconnaissance mapping of the shorelines by the Wrights (1908) and by Buddington and Chapin (1929) in connection with their geologic investigations of southeastern Alaska. The copper prospects are mentioned in several U.S. Geological Survey bulletins dealing with the mineral resources of Alaska between 1907 and 1917, and they are briefly described by Chapin (1917). The Nelson and Tift gold mine is also briefly mentioned in several U.S. Geological Survey bulletins (Smith, 1938, p. 18, 19; 1939, p. 21; 1941, p. 20; 1942, p. 21).

This investigation was carried out by the U.S. Geological Survey on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission. The writer is grateful to the many people who facilitated the field and laboratory work entailed in this report, especially to A. L. Kimball, who capably served as geologic field assistant during the summers of 1956 and 1957 and mapped part of the area. V. L. Freeman was largely responsible for delineating the area that was mapped; L. W. Carson, Jr. assisted in the field for 3 weeks during the summer of 1958; and D. L. Forbes, R. B. Harrist, and Richard Borch at different times served as boatmen. P. H. West, E. C. Morris, and Kenji Sakamoto aided in the laboratory investigations for short periods. Spectrographic and chemical analyses were made by members of the U.S. Geological Survey. The mapping was facilitated by an excellent topographic base map prepared by K. M. Tagg with a Kelsh plotter. This map also includes linear elements of the geology and shows cleared area, densely forested regions, and various cultural features. Helpful cooperation was given by many people connected with the Climax Molybdenum Co. and the Kendrick Bay Mining Co., particularly R. J. O'Hara and Harold Wright. All of the mining people, prospectors, and Ketchikan residents met during the course of fieldwork were helpful and cooperative.

GENERAL GEOLOGIC SETTING

Most of the Bokan Mountain uranium-thorium area is underlain by plutonic rocks similar to those that are exposed over much of the extreme southern part of Prince of Wales Island. Metamorphosed Devonian volcanic and sedimentary rocks border the plutonic rocks to the north and west, forming a large fold that trends northwestward (Buddington and Chapin, 1929, pl. 1). The arcuate contact between the plutonic rocks and the Devonian rocks extends from the southern tip of Prince of Wales Island to the shores of Clarence Strait south of Moira Sound (Buddington and Chapin, 1929, pl. 1). The Devonian rocks are bordered on the north by the older Paleozoic rocks of the Wales group, but they reappear farther north on Prince of Wales Island, about at the latitude of Ketchikan, where they form part of the Prince of Wales-Kuiu anticlinorium (Buddington and Chapin, 1929, pl. 1 and p. 290). A thick belt of Mesozoic sedimentary and volcanic rocks intervenes between the predominantly Paleozoic sedimentary and volcanic rocks of Prince of Wales Island and the rocks of the Coast Range batholith that occupy much of the mainland to the east (Buddington and Chapin, 1929, pl. 1). Twenhofel and Sainsbury (1958, p. 1436) believe that a large fault, termed by them "the Clarence Strait lineament," parallels and underlies Clarence Strait and separates the rocks of Prince of Wales Island from the predominantly Mesozoic rocks to the east.

ROCKS

The Bokan Mountain uranium-thorium area is underlain largely by a complex assemblage of plutonic rocks that ranges in composition from pyroxenite to syenite and peralkaline granite. Quartz diorite, diorite, granodiorite, and quartz monzonite are the most abundant types. Metamorphic rocks are fairly abundant in the northern part of the area but sparsely distributed elsewhere, and dikes, which include many lithologic varieties, are widespread.

METAMORPHIC ROCKS

The metamorphic rocks are divided into the following six units: (1) Metavolcanic rocks, (2) slate, (3) gneiss, (4) schist, (5) amphibolite, and (6) marble and calc-hornfels (pl. 1). The metamorphic rocks underlie about 3 square miles of the northern part of the area, but elsewhere they are exposed mainly as small screens or pendants. They were intruded by the plutonic rocks, but owing to their occurrences in isolated bodies that consist largely of one rock type, little is known about their intrarelation.

METAVOLCANIC ROCKS

DISTRIBUTION AND RELATION

Metavolcanic rocks are exposed in the extreme northwestern part of the area and extend southwestward from the northern boundary, near lat. 54°57′30″ N., to about a mile east of the head of the South Arm of Moira Sound. Their best exposures are along the shores of the South Arm of Moira Sound where they are highly fractured and intruded by several salients of quartz diorite. The metavolcanic rocks are mainly bounded on the south by quartz monzonite and by quartz diorite, both of which intrude them, but in places they are in contact with slate. They are cut by a few fine-grained generally mafic dikes that have a nearly vertical dip. Contacts between the metavolcanic rocks and the dioritic rocks are generally steep, but the contact relations between the metavolcanic rocks and the quartz monzonite and the black slate are obscure.

The metavolcanic rocks apparently consist of a layered flow sequence with individual flows ranging from 1 to 20 feet in thickness. No reasonable estimate of their total thickness can be made because neither the top or the bottom of the unit is known for sure, and additional complications are caused by numerous faults and salients of quartz diorite.

Flow banding is well developed in most of the metavolcanic rocks. Northwest of the South Arm of Moira Sound the flow banding dips nearly vertically and strikes between N. 50° W. and N. 70° W.—nearly parallel with the regional trend of the volcanic rocks as indicated by Buddington and Chapin (1929, pl. 1). Southeast of the South Arm of Moira Sound its strikes range from N. 75° E. to N. 5° W., and it dips from 40° SE. to vertical.

PETROLOGY AND PETROGRAPHY

The metavolcanic rocks are light or medium gray on fresh surfaces and weather a greenish gray, greenish brown, or brown. Less common variants are dark gray and weather dark brown. They include several lithologic types, of which most are probably quartz keratophyre, but identifications are difficult because of their fine grain size and abundant alteration. Thin-section study reveals that these rocks are characteristically porphyritic, commonly consisting of medium-grained phenocrysts in a very fine grained groundmass. Locally they have a spherulitic texture and in some places are cataclastic. Many of the groundmasses are devitrified glass and commonly consist of very fine grained felty masses of feldspar intermixed with chalcedony. In places the groundmass textures are pilotaxitic, but in many specimens textural details are obscured by alteration. Some thin sections reveal lathlike plagioclase crystals oriented along probable flow planes that conform to the outlines of adjacent phenocrysts.

The following terms are used to describe average grain sizes of minerals in this report:

Grain size	*Millimeters*
Very fine grained	<0.5
Fine grained	0.5–1.0
Medium grained	1.0–3.0
Coarse medium grained	3.0–5.0
Coarse grained	>5.0

The phenocrysts are commonly subhedral or euhedral and consist of plagioclase, chiefly albite, and K-feldspar. Quartz phenocrysts occur in a few of the rocks.

The principal groundmass minerals are plagioclase, chiefly albite, quartz, and chalcedony. K-feldspar is generally less abundant, and chlorite, clay minerals, or calcite prevail in some altered groundmasses. Biotite, in fine-grained subhedral crystals, forms as much as 5 percent of some of the thin sections. Its pleochroism is X, yellow brown; and Y and Z, dark brown. The accessory minerals include apatite, sphene, zircon(?), and opaque minerals. The opaque minerals consist of pyrite and very minor amounts of magnetite and chalcopyrite(?). The less common secondary minerals are clinozoisite, after plagioclase; sericite, after feldspars; epidote, after mafic minerals; and in veinlets, hematite(?) after limonite(?) after magnetite and pyrite; and leucoxene(?) and sphene.

The results of semiquantitative spectrographic analyses and of equivalent and chemical uranium analyses of three typical metavolcanic rocks are shown in table 12 (Nos. 56AMK–238, –240, –261).

SLATE

DISTRIBUTION AND RELATION

The slate forms a crudely semicircular band around the boss of Bokan Mountain granite and extends from Hill 2302 to near the extreme northeastern part of the area (pl. 1). These rocks are best exposed in Hill 2302 where they have an apparent thickness of about a thousand feet—a minimum value because neither their base nor top is exposed. Some impure quartzite and marble occur within this unit. The quartzite is exposed in some pits at the Cheri claims about half a mile south of the head of the West Arm of Kendrick Bay, and the marble, which occurs as intercalated beds from 1 to 6 feet thick, is exposed in a canyon about a mile S. 70° E. of the head of the South Arm of Moira Sound. The slate unit has been intruded by the Bokan Mountain granite, quartz monzonite, granodiorite, quartz diorite, diorite, and aplite, but in some places is in fault contact with these rocks. Contact relations are obscure in the slate's northernmost exposures where it is adjacent to metavolcanic rocks.

Bedding in the slate is generally difficult to see; where it is discernible, it is manifested by laminae of contrasting colors 1 to 3 mm thick. The slate locally has been folded into a series of open flexures that strike northwestward; their limbs generally dip southwestward or northeastward at less than 45°. Two sets of steep cleavage are conspicuous in the slate. The cleavage ranges widely in strike but generally dips between 70° and vertical.

PETROLOGY AND PETROGRAPHY

Black carbonaceous slate is the predominant rock, but phyllite, fine-grained impure quartzite, metasiltstone, hornfels, and very minor amounts of fine-grained amphibolite, marble, and graywacke are included in this unit. The slate commonly is black or dark gray on fresh surfaces and weathers black or dark brown. Its megascopic minerals are chiastolite, pyrite, which occurs in disseminations or fracture coatings, and sparse quantities of graphite. The phyllite is moderately abundant and has foliation manifested by the micas. The metasiltstone is very fine grained dark-gray to black rock, which generally is rich in organic material and is practically indistinguishable from slate in the field. Hornfels occurs near some of the intrusive contacts and is very fine grained, medium gray, and brown weathering.

Thin sections of the black slate reveal that it is very fine grained foliated rock, and some has porphyroblastic textures. Its chief constituents are extremely fine grained quartz, clay minerals, and graphite. In places the black slate contains chiastolite porphyroblasts from 2 to 10 mm long, sericite, disseminated pyrite, and minor amounts of feldspars, biotite, chlorite, magnetite, limonite(?), and leucoxene(?). Prismatic aggregates and rosettes of gypsum locally coat fracture surfaces, where they probably formed from reactions between calcium-bearing water and sulfate ions derived from the oxidation of pyrite.

The metasiltstone is similar to the black slate in composition but consists largely of silt-size quartz grains. In addition to the minerals of the black slate, some metasiltstone contains tremolite and calcite. The impure quartzite at the Cheri claims consists largely of well-sorted subrounded quartz grains about a millimeter in diameter. Some of the quartz grains have secondary overgrowths, Boehm lamellae, and rutile(?) inclusions concentrically distributed near their peripheries. Intergranular interstices are occupied by hematite, allanite, probably other uranium and rare-earth-bearing minerals, and by minor amounts of plagioclase, hornblende, chlorite, and epidote.

The marble that is interbedded with the slate consists of about 90 percent calcite, which forms a granular aggregate with an average grain size of about 1 mm. The calcite has been bent and granulated, and very fine grained cataclastic calcite commonly separates the coarser grains. Tremolite, pyrite, graphite, sericite, and quartz occur in minor amounts in the marble.

The results of semiquantitative spectrographic analyses and equivalent and chemical uranium analyses of a black slate and a metasiltstone are shown in table 12 (Nos. 56AMK–113, –230). An analysis of a black slate and its specific gravity (sp gr) are shown in table 1.

TABLE 1.—*Chemical analyses (in weight percent) of the metamorphic rocks*

[Analysts, P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M.D. Mack, U.S. Geol. Survey, 1958]

	1	2		1	2
SiO_2	64.6	46.1	TiO_2	.40	1.0
Al_2O_3	8.7	18.8	P_2O_5	.08	.20
Fe_2O_3	2.0	1.1	MnO	.01	.16
FeO	1.5	9.4	CO_2	.06	$<.05$
MgO	.87	8.7	Organic matter	16.6	--------
CaO	.42	7.4			
Na_2O	.48	2.9	Sum	99.62	99.32
K_2O	2.2	.51			
H_2O	1.7	3.0	Sp. Gr.	2.53	2.91

1. Black slate, 7,200 ft N. 72° W. of Bokan Mountain.
2. Andesine-biotite-hornblende schist, south shore of Kendrick Bay, 5,100 ft S. 42½° W. of beacon "Drick.'

GNEISS

DISTRIBUTION AND RELATION

Gneiss forms several small roof pendants within the intrusive rocks; the largest extends westward from McLean Point for about 3,000 feet and attains a maximum width of 1,500 feet (pl. 1). Small exposures of similar rock along the southern shores of the eastern part of McLean Arm are probably extensions of this body. Another small roof pendant of gneiss crops out about 1½ miles southeast of Hessa Lake. Other small gneiss pendants lie within quartz monzonite and granodiorite. Most of the contacts between the gneiss and the intrusive rocks have steep dips and are fairly sharp, but in places the contacts are gradational over zones 10 to 30 feet wide that are marked by numerous intrusive salients penetrating the gneiss. The gneiss is characterized by well-developed foliation that commonly is parallel both to the lengths of the pendants and to the foliation of the adjacent intrusive rocks.

PETROLOGY AND PETROGRAPHY

The gneiss commonly is a very fine or fine-grained rock of alternating white or light-gray and dark-gray bands each a few millimeters thick. Its weathered surfaces are generally light or medium brown. The dark-gray bands consist chiefly of biotite or hornblende that have parallel or subparallel orientations. The pleochroism of the biotite is tan to reddish brown, and that of the hornblende is X, light yellow brown; Y and Z, green. The light-colored bands are largely composed of more or less equigranular quartz and plagioclase, sodic andesine or calcic oligoclase. K-feldspar constitutes less than 5 percent of the gneiss. Lesser constituents of the gneiss are muscovite, sphene, pyrite, magnetite, ilmenite, and monazite(?). The secondary minerals are calcite, clinozoisite, actinolite, clay minerals, epidote, sericite, chlorite, hematite, limonite(?), and leucoxene(?).

Most of the gneiss is probably paragneiss, but some of it may be of igneous origin.

SCHIST

DISTRIBUTION AND RELATION

Schist is exposed in small screens and roof pendants on many of the Kendrick Islands and on nearby parts of Prince of Wales Island. It is in contact with quartz diorite, diorite, and gneissic quartz monzonite, and to lesser extents with quartz monzonite, granodiorite, and amphibolite. The contacts are steep and many are gradational over distances of as much as 50 feet. The gradational contacts are marked by abundant elongate schist inclusions near the borders of the intrusive rocks and by salients of intrusive rocks penetrating schist, generally parallel to the foliation. Several types of dikes cut the schist, and some of these, particularly the pegmatites and aplites, tend to be parallel to the foliation in the schist.

PETROLOGY AND PETROGRAPHY

The schist is mafic rock that is medium or dark gray and weathers brown. The dominant variety mapped as schist is very fine grained and has well-developed foliation; some others having a gneissic texture, and a few rocks having an equigranular aspect of very fine grained granulites, are also included with the schist. Mullion structures that plunge steeply and appear to be alined with minor fold axes characterize some schist. Some of the schist is characterized by felsic augen a few millimeters long; other contains abundant disseminated pyrite; and some is cut by numerous epidote-rich veinlets.

Bedding, where discernible, ranges from about 1 to 4 feet in thickness and is parallel with foliation, but there are large tracts of schist that apparently lack bedding. Foliation in the schist, which is best shown by alined hornblende and biotite, commonly is parallel to the foliation of the adjacent intrustive rocks. It principally trends northward to northwestward and mainly dips westward between 70° and vertical.

The mineralogy of the schist indicates that it is in the amphibolite metamorphic facies as described by Turner and Verhoogen (1951, p. 446).

Most of the schist contains abundant hornblende and plagioclase, commonly andesine, and some biotite. The pleochroism of the biotite is colorless to red brown or tan to greenish brown and that of the hornblende is X, tan; Y and Z, greenish brown or green. Quartz, which is generally uncommon in the schist, is abundant in a few of the granulites. Actinolite is fairly abundant in some of the schist. Its pleochrism is X and Y, colorless; Z, light green. K-feldspar and muscovite occur in small amounts in some of the schist. Minor accessory minerals in the schist include apatite, sphene, magnetite, pyrite, ilmenite(?), chalcopyrite(?), and allanite(?). The secondary minerals are chlorite, which is fairly abundant, hematite, limonite(?), calcite, clay minerals, epidote, clinozoisite, and sericite.

Two analyses of schist are shown in table 12 (Nos. 57 AMK–94, –97). The results of a rapid-method chemical analysis of a schist and its specific gravity (sp gr) are shown in table 1.

The limited data indicate that in schist near intrusive rocks hornblende is the dominant mafic mineral and that plagioclase is slightly enriched in the anorthite molecule.

The schist differs from the gneiss by texture, by containing a higher percentage of mafic minerals and less abundant quartz and by being finer grained.

AMPHIBOLITE

DISTRIBUTION AND RELATION

Amphibolite crops out in elongate pendantlike masses near the Short and South Arms of Kendrick Bay (pl. 1). It is also exposed on the westernmost Kendrick Island and north of this island on the north shore of Kendrick Bay. Minor quantities of amphibolite, too small to show on the geologic map, occur in some of the quartz diorite and diorite near the West Arm of Kendrick Bay. The largest body of amphibolite is traceable for a length of about 8,000 feet and attains a maximum width of about 800 feet.

The amphibolite on the north shore of Kendrick Bay intervenes between quartz diorite and schist. Elsewhere amphibolite is in contact with either quartz monzonite, granodiorite, diorite, or quartz diorite. The contacts generally dip steeply, and those with plutonic rocks are commonly gradational, being marked by a progressive increase in the amount of mafic inclusions in the invading rock and by hybrid zones in which fine-grained felsic rock is intermixed with amphibolite and fine-grained quartz diorite. Fine-grained mafic-rich dikes and aplite and pegmatite dikes cut the amphibolite.

PETROLOGY AND PETROGRAPHY

The amphibolite is dark-green or dark-greenish-brown rock that is chiefly coarse grained. Some of the amphibolite, particularly near contacts, is intermixed with fine-grained leucocratic rock and quartz diorite. This association is characterized by abundant hornblende-rich clots separated by small amounts of the leucocratic rock, or by swarms of numerous irregularly trending leucocratic dikes a few centimeters thick cutting the amphibolite. In places irregular blocks of amphibolite are in a matrix of fine-grained quartz diorite or diorite and resemble an intrusive breccia similar to the ones described by Kinkel and others (1956, p. 73) from the West Shasta district in California.

The amphibolite is believed to represent mafic rock that recrystallized and differentiated into the prevailing hornblende-rich parts and the subordinate fine-grained leucocratic parts. In places the resulting assemblage was intimately invaded and injected by fine-grained dioritic rocks.

The size, shape, and distribution of the amphibolite bodies probably favor a metamorphic origin for most of them, and the lack of planar or linear structures probably indicates that the amphibolite was relatively unstressed when formed. Whether or not all the amphibolite is of metamorphic origin is enigmatic, and an igneous origin involving fractionation or fractional resorption and differentiation as demonstrated by Bowen (1928, p. 270, 271) for some hornblendite cannot be precluded.

The amphibolite is coarse-grained altered rock that commonly contains between 50 and 90 percent hornblende. The hornblende commonly forms subhedral crystals about 1 cm long, but locally attains lengths of 2 cm. Its pleochroism is X, tan; Y and Z, brown or green. The hornblende contains numerous poikilitic inclusions. Plagioclase is moderately abundant in the amphibolite. It is sodic andesine where determinable, but much of it is strongly altered. Epidote is the prevalent alteration product, and augite, pyrite, and other opaque minerals, sphene, and apatite, are the subordinate minerals. Modal analyses of two thin sections of amphibolite, based on the point-count method of Chayes (1949), are shown in table 2.

TABLE 2.—*Modal analyses of two amphibolites*

Mineral	Percent	
	57AM*K*-10	57AM*K*-24
Hornblende	57	69
Plagioclase	30	14
Augite	2	2
Opaque minerals	<1	<1
Apatite	<1	<1
Sphene	<1	----------
Epidote and clinozoisite	6	11
Chlorite	3	3
Clay minerals	1	<1
Sericite	<1	----------

MARBLE AND CALC-HORNFELS

DISTRIBUTION AND RELATION

Marble and calc-hornfels crop out in four narrow bodies along the north side of McLean Arm. At least three of these are faulted parts of the same original mass, a pendant in quartz diorite. The largest body is exposed at and near the Nelson and Tift gold mine, about three-quarters of a mile from the entrance to McLean Arm (pl. 5). It is traceable for about 1,000 feet and is about 35 feet wide. Away from the shoreline, areas that are underlain by marble are marked by troughlike depressions.

The marble and calc-hornfels bodies trend from N. 70° W. to west, dip steeply, and have been intruded by quartz diorite and diorite. The contacts with the dioritic rocks are sharp and are marked by contact metamorphic effects in the adjacent calcareous rocks, and in places are loci for the deposition of quartz and pyrite. A few small remnants of chert nodules and lenses are in the marble and calc-hornfels (pl. 5).

PETROLOGY AND PETROGRAPHY

These rocks consist largely of marble that commonly has either bands or irregular patches of calc-hornfels near its contacts with the intrusive rocks. Generally the calc-hornfels occurs in two discrete zones. The one closest to the intrusive contact is from 2 to 12 inches thick and is rich in a cinnamon-colored garnet; the other, an intermediate zone of similar thickness, intervenes between the garnet-rich zone and the marble and consists almost entirely of tremolite. Both the marble and the tremolite-rich zone are light gray or white. Minor calcite veins cut the marble and the adjacent rocks.

The mineralogy of the marble and calc-hornfels is fairly simple. The marble consists mainly of granoblastic calcite commonly in crystals between 5 and 8 mm in diameter but to lesser extents in fine- or medium-grained crystals. Minor constituents of the marble are quartz, phlogopite(?), clay minerals, and disseminated pyrite. In places the marble is flecked with dark opaque minerals, chiefly magnetite and probably some graphite. Some of the calcite crystals have twin lamellae along which small displacement has occurred. The tremolite in the light-colored calc-hornfels is in crystals 2 or 3 cm long. The cinnamon-colored massive appearing garnet in the outer zone is in the grossularite-andradite series, $n=1.787$ and specific gravity=3.59. These determinations were made with immersion oils and a Berman balance, and the resulting data compared with figure 378 in Winchell and Winchell (1951, p. 485). Generally the garnet-rich rock contains minor amounts of quartz and disseminated pyrite.

AGE AND CORRELATION

According to Buddington and Chapin (1929, p. 94, 95, 96, and pl. 1) the prebatholithic rocks of the southern part of Prince of Wales Island are Devonian in age and are divisible into three units: a lowermost volcanic unit that consists chiefly of flows and breccias, an intermediate unit consisting of tuffaceous sedimentary rock and interbedded black slate and limestone that locally contains Middle Devonian fossils, and a Middle Devonian unit stratigraphically higher consisting largely of limestone. Buddington and Chaplin (1929, p. 97) believe that the southernmost belt of Devonian rocks on Prince of Wales Island forms a large syncline, and within the Bokan Mountain uranium-thorium area they have mapped their lower and intermediate Devonian units in the vicinity of Moira Sound.

A postulated correlation based largely on lithology but supplemented by the probable synclinal structure between the Bokan Mountain area metamorphic rocks and the Devonian rocks of Buddington and Chapin (1929) is shown as follows:

Bokan Mountain uranium-thorium area (this report)	*Southern part of Prince of Wales Island (Buddington and Chapin, 1929)*
Marble and calc-hornfels	Limestone.
Slate, gneiss, schist, and amphibolite	Sedimentary rock including graywacke, conglomerate, and slate and associated volcanics.
Metavolcanic rocks, chiefly quartz keratophyre.	Andestitic lava, breccia, and conglomerate with cobbles of limestone.

The following factors, however, cast some doubt on the preceding correlation: no fossils were found within the area mapped, some of the gneiss and amphibolite may be of igneous origin, and the stratigraphic relations are obscure in the Bokan Mountain uranium-thorium area.

PLUTONIC ROCKS

Plutonic rocks, which underlie most of the area, form masses of diverse sizes and outcrop patterns and include many lithologic types. Compositionally they range from pyroxenite and gabbro to syenite and peralkaline granite but are mainly diorite, quartz diorite, granodiorite, and quartz monzonite.

The plutonic rocks were divided into seven units for mapping purposes. Arranged in their order of probable decreasing age these are pyroxenite, gabbro, quartz diorite and diorite, quartz monzonite and granodiorite, gneissic quartz monzonite, syenite, and peralkaline granite. The chronological order of most of this sequence is well substantiated by field relations, but in part it is doubtful because contacts between some of the plutonic rocks are lacking or nondiagnostic. Some of the units contain more than one lithologic type, the result of either the impracticability or the difficulty in differentiating them in the field. For example, the quartz diorite unit includes minor amounts of amphibolite, gabbro, and schist; the quartz monzonite and granodiorite have local leucocratic and granite facies; and the syenite imperceptibly grades into monzonite. Many of the plutonic rocks are sodium rich, and some of them have been albitized. The peralkaline granite is of interest both because it is an uncommon rock and because most of the uranium-thorium deposits in the area are believed to be genetically related to it.

Judging from the nature of internal structures, or the lack of them, and the forms of the intrusive bodies and their field relations, the gneissic quartz monzonite and older plutonic rocks with the exception of the pyroxenite probably were largely syntectonic intrusions, whereas the peralkaline granite and the syenite appear to be post-tectonic.

Magmatic stoping probably was an important mechanism during the intrusion of some of the plutonic rocks. This process is indicated by the numerous xenoliths and the development of intrusive breccias near many of the contacts (fig. 2). Probable results of forceful intrusion are the crudely arcuate pattern of the slate around the boss of peralkaline granite and minor folds in some of the metamorphic rocks.

One can reasonably postulate that the bulk of the plutonic rocks, excluding the syenites, monzonites, and ultramafic rocks, are differentiates from the same parent magma. Such a genesis is indicated by the distribution of the plots of the norms of the granitic rocks (fig. 4), which show a general evolution from the older dioritic rocks to the younger peralkaline granite and a corresponding progression toward the thermal valley of the residual magmatic system (Bowen, 1937). The field relations between the rocks also indicate a differentiate origin. The quartz diorite and diorite masses generally have a fine-grained border zone that is contaminated with numerous inclusions and contains abundant hornblende. Progressing centripetally into the plutons, the border zones commonly give way to a medium-grained zone that contains few inclusions and more quartz and plagioclase, and these zones locally grade into granodiorite and quartz monzonite. At some places, however, quartz monzonite or granodiorite is in contact with older rocks without intervening quartz diorite or diorite. Perhaps these occurrences are indicative of physical and chemical conditions unfavorable to differentiation, or the intrusion of still mobile quartz monzonite subsequent to the solidification of the diorite and quartz diorite. The fine-grained textures, high degree of contamination, and relict sedimentary features in some of the dioritic border zones indicate that these rocks were partly formed by the metasomatism of preexisting rocks.

PYROXENITE

DISTRIBUTION AND RELATION

Pyroxenite crops out in four discrete elongate bodies in the southern part of the area; three of these are best exposed on the shores of Stone Rock Bay and the fourth along the south shore of Mallard Bay (pl. 1). The small body of pyroxenite that crops out along the south shore near the head of McLean Arm is probably a faulted extension of the Mallard Bay pyroxenite mass. The largest pyroxenite body is at least 8,000 feet long and 1,000 feet wide.

The pyroxenite is mainly in contact with quartz monzonite and syenite, both of which intrude it, but a small amount of pyroxenite has been intruded by quartz diorite. A few aplite, syenite, and andesite(?) dikes cut the pyroxenite. Commonly the contacts between pyroxenite and quartz monzonite are gradational through a zone of hybrid rock or intrusive breccia between 30 and 70 feet thick that contains abundant pyroxenite xenoliths (fig. 2). Contacts between pyroxenite and syenite or quartz diorite are sharper and mainly appear to be steep. The pyroxenite is cut by numerous faults and locally is strongly sheared although internal planar or linear structures are generally poorly developed or absent.

PETROLOGY AND PETROGRAPHY

The pyroxenite is a dark-gray rock that is flecked with brown biotite. It is generally hypidiomorphic granular in texture and consists chiefly of augite in subhedral crystals with dimensions between 2 and 5 mm but locally is porphyritic and contains abundant euhedral augite phenocrysts in a plagioclase-rich groundmass. Other minerals include hornblende, which is chiefly uralitic after augite but to a lesser extent occurs as a primary mineral, plagioclase (labradorite), biotite, magnetite, apatite, epidote and very minor amounts of sphene, clay minerals, calcite, chlorite, quartz, and sericite. Locally biotite and hornblende are present in sufficient amounts for this rock to be called a biotite-hornblende pyroxenite or biotite pyroxenite; according to Johannsen (1939, pt. 2, p. 450) these varieties are uncommon. The pleochroism of the biotite is X, colorless; Y and Z, brown. Most of the pyroxenite is fairly fresh, but in some places it is altered to masses that are rich in epidote, chlorite, and clay minerals. A few quartz-epidote veinlets cut the pyroxenite. Figure 3 is a photomicrograph that shows the typical minerals of the pyroxenite. The results of modal analyses of three thin sections of pyroxenite, following the point-count method of Chayes (1949), are shown in table 3 (Nos. 1–3).

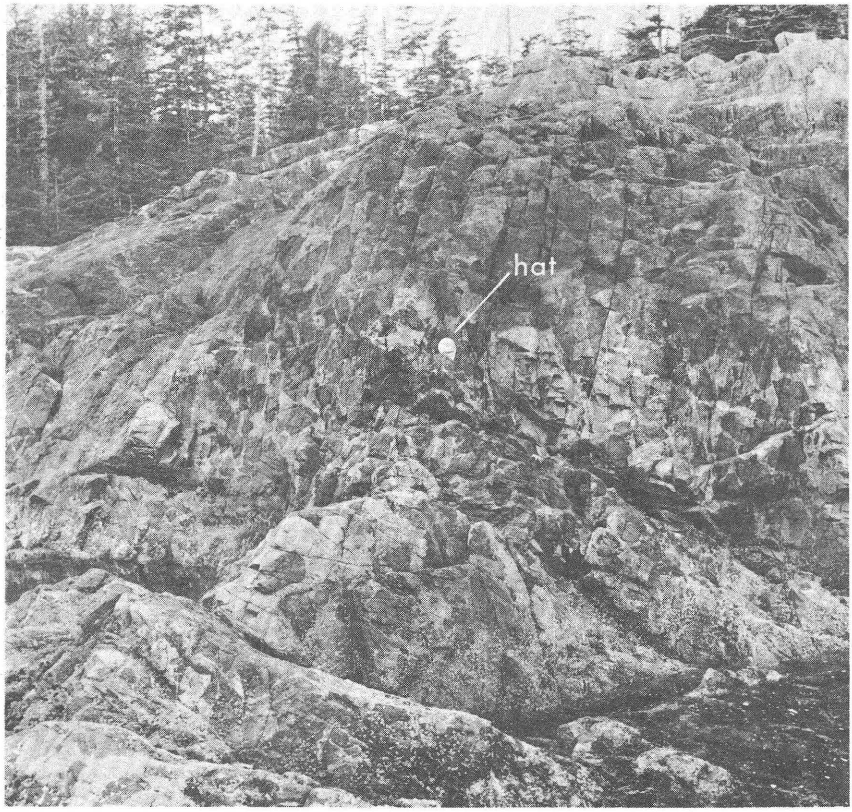

FIGURE 2.—Pyroxenite xenoliths and quartz monzonite in a hybrid zone, shore of Stone Rock Bay. (Note hat for scale.)

Samples 1 and 3 are from near Stone Rock Bay, and sample 2 is from the Mallard Bay pyroxenite mass. Some of the pyroxenites contain much more magnetite than is indicated by the modal analyses and constitute potential iron ores.

The results of semiquantitative spectrographic analyses and equivalent and chemical uranium analyses of a pyroxenite are shown in table 13 (No. 57AMK–110).

GABBRO

DISTRIBUTION AND RELATION

The gabbro occurs at a number of places chiefly near borders of the dioritic rocks, but only three small gabbro masses are shown on plate 1. These include one along the south shore of Kendrick Bay east of the mouth of the South Arm and two others near the head of McLean Arm. Other areas of gabbro too small to map, which also are associated with diorite, were found near the head of the South

FIGURE 3.—Photomicrograph of pyroxenite showing augite, A; biotite, B; hornblende, H; and magnetite, the opaque mineral. Ordinary light (× 12).

Arm of Moira Sound and southeast of the West Arm of Kendrick Bay. Exceptions to the gabbro-diorite relation were found near the head of McLean Arm, where the northernmost of two gabbro masses is partly in contact with quartz monzonite and granodiorite that has invaded it, and the southernmost one is partly bounded by a steep fault that separates it from syenite. Most contacts are gradational and difficult to map accurately. A few fine-grained mafic dikes cut the gabbro.

PETROLOGY AND PETROGRAPHY

The gabbro is a dark-gray rock that is medium grained with minor fine-grained variants. It generally is equigranular with hypidiomorphic granular textures. Alteration has pervaded a few of the gabbro masses, particularly those near McLean Arm, and in places has obliterated many primary mineralogical and textural details. The gabbro appears similar to some of the diorite with which it is closely associated, and the two rocks are difficult to differentiate in the field. Factors that help to differentiate the gabbro from the dioritic rocks are the paucity of quartz and sphene in the gabbro, its equigranular textures, less abundant hornblende, and commonly its less conspicuous planar and linear structures.

TABLE 3.—*Modal analyses, in volume percent, of the plutonic rocks*

[Lab = labradorite; m = magnetite]

Mineral	Pyroxenite			Gabbro			Albitized diorite			Albitized quartz diorite		
	1	2	3	4	5	6	7	8	9	10	11	12
Quartz	------	2	<1	<1	1	------	4	4	<1	9	16	22
Plagioclase	<1 (Lab)	29 (Lab)	<1 (Lab)	60 An_{51}	59 An_{52}	76 An_{75-65}	43 An_{8}	31 An_{6}	48 An_{9}	48 An_{9}	58 An_{6}	54 An_{4}
K-feldspar	------	------	------	------	1	------	<1	3	------	1	2	2
Hornblende	16	------	14	------	23	------	47	49	44	30	20	------
Biotite	6	9	10	<1	9	------	------	------	------	2	------	------
Augite	63	42	65	13	3	8	------	------	------	------	------	------
Apatite	1	1	<1	------	<1	1	<1	<1	<1	<1	<1	<1
Sphene	<1	------	<1	------	------	------	<1	<1	<1	<1	1	<1
Acmite	------	------	------	------	------	------	------	------	------	------	------	------
Riebeckite	------	------	------	------	------	------	------	------	------	------	------	------
Pyrite	------	------	------	<1	------	------	<1	2	<1	1	------	1
Opaque minerals (excluding pyrite)	9 (m)	3 (m)	10 (m)	2	1	2	<1	1	------	<1	3	<1
Monazite	------	------	------	------	------	------	------	------	------	<1	------	<1
Zircon	------	------	------	------	------	------	------	------	------	------	------	------
Allanite	------	------	------	------	------	------	------	------	------	------	------	------
Cordierite	------	------	------	------	------	------	------	------	------	------	------	------
Fluorite	------	------	------	------	------	------	------	------	------	------	------	------
Uranothorite	------	------	------	------	------	------	------	------	------	------	------	------
Xenotime	------	------	------	------	------	------	------	------	------	------	------	------
Epidote	4	2	<1	<1	<1	5	3	5	4	5	<1	12
Clay minerals	<1	<1	<1	1	<1	------	<1	<1	<1	<1	<1	<1
Chlorite	<1	11	<1	8	2	5	1	3	2	<1	<1	8
Sericite	<1	<1	------	------	------	------	------	------	<1	------	------	------
Calcite	------	<1	<1	------	------	------	------	------	<1	------	<1	------
Tremolite	------	------	------	13	<1	3	------	------	<1	------	------	------
Clinozoisite	------	------	------	------	------	------	<1	------	------	<1	------	<1
Thomsonite	------	------	------	------	------	------	------	------	------	------	------	------

Mineral	Diorite			Quartz diorite			Albitized granodiorite		
	13	14	15	16	17	18	19	20	21
Quartz	<1	<1	<1	24	9	13	41	28	25
Plagioclase	66 An_{50-45}	56 An_{40}	69 An_{32-25}	58 An_{18}	68 An_{37-32}	69 An_{50-27}	41 An_{8}	46 An_{8}	47 An_{6}
K-feldspar	<1	------	------	4	4	2	17	19	21
Hornblende	32	39	22	1	13	12	------	------	------
Biotite	------	------	------	9	1	1	------	------	6
Augite	------	------	------	------	------	------	------	------	------
Apatite	------	<1	<1	<1	<1	<1	------	------	<1
Sphene	<1	------	1	------	<1	<1	------	------	------
Acmite	------	------	------	------	------	------	------	------	------
Riebeckite	------	------	------	------	------	------	------	------	------
Pyrite	------	<1	<1	<1	------	------	<1	<1	------
Opaque minerals (excluding pyrite)	<1	<1	1	<1	<1	<1	------	------	<1
Monazite	------	------	------	------	------	------	<1	<1	------
Zircon	------	<1	------	<1	<1	<1	------	------	<1
Allanite	------	------	------	------	------	------	------	------	------
Cordierite	------	------	------	------	------	------	------	------	------
Fluorite	------	------	------	------	------	------	------	------	------
Uranothorite	------	------	------	------	------	------	------	------	------
Xenotime	------	------	------	------	------	------	------	------	------
Epidote	<1	<1	<1	<1	1	<1	------	------	<1
Clay minerals	<1	1	<1	1	1	<1	<1	1	<1
Chlorite	1	1	5	2	1	<1	1	4	<1
Sericite	------	<1	<1	------	------	------	<1	------	------
Calcite	------	<1	<1	------	------	------	------	1	------
Tremolite	------	------	------	------	------	------	------	------	------
Clinozoisite	1	<1	------	------	------	<1	<1	------	------
Thomsonite	------	------	------	------	------	------	------	<1	------

TABLE 3.—*Modal analyses in volume percent, of the plutonic rocks*—Continued

Mineral	Albitized quartz monzonite			Granodiorite			Quartz monzonite		
	22	23	24	25	26	27	28	29	30
Quartz	20	32	36	22	15	19	27	36	25
Plagioclase	43 An$_8$	35 An$_6$	37 An$_8$	45 An$_{28-20}$	53 An$_{35-30}$	50 An$_{28-25}$	43 An$_{27-20}$	32 An$_{14}$	44 An$_{35-25}$
K-feldspar	29	27	25	20	17	10	23	29	22
Hornblende	---	---	---	---	10	10	---	---	5
Biotite	4	2	<1	10	<1	7	5	2	<1
Augite	---	---	---	---	---	---	---	---	---
Apatite	---	---	---	<1	<1	<1	<1	---	<1
Sphene	---	---	---	<1	1	1	<1	<1	<1
Acmite	---	---	---	---	---	---	---	---	---
Riebeckite	---	---	---	---	---	---	---	---	---
Pyrite	---	---	<1	<1	---	<1	---	---	---
Opaque minerals (excluding pyrite)	<1	3	<1	<1	1	1	<1	<1	<1
Monazite	<1	---	---	---	---	---	---	---	---
Zircon	---	<1	<1	<1	<1	<1	<1	<1	<1
Allanite	---	---	---	---	---	---	---	<1	---
Cordierite	---	---	---	---	---	---	---	---	---
Fluorite	---	---	---	---	---	---	---	---	---
Uranothorite	---	---	---	---	---	---	---	---	---
Xenotime	---	---	---	---	---	---	---	---	---
Epidote	---	---	---	<1	<1	<1	<1	---	<1
Clay minerals	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chlorite	4	<1	<1	---	2	1	<1	<1	3
Sericite	---	---	---	---	---	<1	<1	<1	<1
Calcite	---	---	---	---	---	<1	---	---	---
Tremolite	---	---	---	---	---	---	---	---	---
Clinozoisite	---	---	---	---	<1	---	---	---	---
Thomsonite	---	---	---	---	---	---	---	---	---

Mineral	Gneissic—		Syenite		Bokan Mountain granite				
	Granodiorite	Quartz monzonite							
	31	32	33	34	35	36	37	38	39
Quartz	43	32	<1	2	43	37	43	36	35
Plagioclase	37 An$_{27-20}$	30 An$_{17-14}$	5 An$_{12}$	13 An$_{20}$	6 An$_8$	16 An$_4$	13 An$_7$	7 An$_4$	11 An$_7$
K-feldspar	17	34	91	84	42	41	35	52	41
Hornblende	---	---	---	---	---	---	---	---	---
Biotite	2	3	1	<1	---	---	---	---	---
Augite	---	---	---	---	---	---	---	---	---
Apatite	<1	<1	<1	---	---	---	---	---	---
Sphene	---	---	<1	<1	---	---	---	---	---
Acmite	---	---	---	---	3	3	5	---	5
Riebeckite	---	---	---	---	4	<1	4	---	5
Pyrite	<1	<1	---	---	---	---	---	<1	<1
Opaque minerals (excluding pyrite)	<1	<1	1	<1	<1	2	<1	<1	<1
Monazite	---	---	---	---	---	---	---	---	---
Zircon	---	<1	<1	<1	1	<1	---	1	<1
Allanite	---	---	---	---	---	---	---	---	---
Cordierite	---	---	---	---	<1	---	---	---	---
Fluorite	---	---	---	---	---	<1	---	<1	<1
Uranothorite	---	---	---	---	---	---	---	<1	<1
Xenotime	---	---	---	---	---	---	---	---	<1
Epidote	<1	---	---	---	---	---	---	---	---
Clay minerals	<1	<1	<1	<1	<1	<1	<1	<1	<1
Chlorite	<1	<1	<1	<1	---	---	---	---	---
Sericite	---	<1	<1	<1	---	---	---	---	---
Calcite	<1	---	<1	---	---	---	---	---	---
Tremolite	---	---	---	---	---	---	---	---	---
Clinozoisite	---	---	---	---	---	---	---	---	---
Thomsonite	---	---	---	---	---	---	<1	---	<1

The gabbro is plagioclase rich and consists largely of albite-twinned labradorite that is slightly normally zoned. Augite is generally the dominant mafic mineral. It has been uralitized to different degrees, and uralitic amphibole is locally abundant, although some of the gabbro contains small quantities of primary hornblende. Biotite occurs in subordinate amounts in most of the gabbro. Its pleochroism is X, colorless; Y and Z, tan, greenish brown, or brown. The minor constituents are disseminated pyrite, quartz, K-feldspar, magnetite, ilmenite(?), apatite, and sphene, and numerous alteration products. Quartz-epidote veinlets cut some of the gabbro. Modal analyses of three thin sections of gabbro are shown in table 3 (Nos. 4, 5, and 6). A semiquantitative spectrographic analysis and equivalent and chemical uranium analyses of a sample from the gabbro body on the south shore of Kendrick Bay are shown in table 13 (No. 57AMK–66B).

QUARTZ DIORITE AND DIORITE

DISTRIBUTION AND RELATION

Quartz diorite and diorite underlie a large part of the mapped area, and, with quartz monzonite and granodiorite, they constitute the dominant rocks. They are the prevailing rocks contiguous to the West Arm of Kendrick Bay and in much of the mountainous terrain between the mouth of the South Arm of Kendrick Bay and McLean Arm. The dioritic rocks are in contact with each of the other rock types that were mapped. They intrude the Devonian metamorphic rocks, the pyroxenite, and the gabbro, and their contact relations with these rocks are described in preceding parts of this paper. The quartz diorite and diorite have been invaded by quartz monzonite and granodiorite, and most of their contacts with these rocks are gradational. Many of these contact zones contain abundant dioritic inclusions ranging from a few inches to about 2 feet in diameter. In some other contact zones the invaded and invading rocks are closely mixed. At a few places these contacts are fairly sharp, and wherever determinable, they are steep. Numerous quartz monzonite or granodiorite apophyses penetrate parts of the quartz diorite or diorite.

Contacts between the dioritic rocks and the gneissic quartz monzonite, which are exposed on the westernmost Kendrick Island and east of the mouth of the South Arm of Kendrick Bay, are gradational over zones 10 to 20 feet wide. These zones, which dip steeply, are marked by apophyses of the gneissic quartz monzonite penetrating the dioritic rocks and by mafic inclusions in the adjacent gneissic quartz monzonite.

The contacts between the dioritic unit and syenite near Stone Rock Bay and south of McLean Arm are poorly exposed, but crosscutting relations indicate that the syenite has intruded the dioritic rocks.

In a few places near the boss of Bokan Mountain granite, both peralkaline granite and aplite have intruded the quartz diorite and diorite, forming sharp and generally steep contacts.

The quartz diorite and diorite are cut by every type of dike that occurs in the area, and most contacts with the dikes are sharp and nearly vertical. Swarms of the prevalent fine-grained mafic dikes and also thin quartz-epidote veins are common within the dioritic rocks.

PETROLOGY AND PETROGRAPHY

The quartz diorite and diorite unit consists largely of about equal amounts of hornblende-quartz diorite and hornblende diorite, but it contains subordinate quantities of rocks in which biotite or augite are the chief mafic minerals. Minor amounts of amphibolite, gabbro, gneiss, and schist occur within the dioritic rocks in masses that are either too small or too obscure to map separately. The dioritic rocks commonly are medium grained or fine grained and have a mottled or speckled aspect. Fine-grained facies are localized near some borders. They commonly contain features such as abundant fine-grained mafic inclusions, some in elongate schlieren with indistinct borders, closely spaced foliation, and banding that may be a relict sedimentary or volcanic structure.

Many of the dioritic rocks in the northwestern part of the area, approximately north of the 54°52′30″ parallel and west of the 132°05 meridian, have been albitized. The approximate extent of the albitized plutonic rocks is shown on plate 1. Narrow albitized prongs extend out from the fringe of the altered zones; these apparently are controlled by faults that penetrate the unalbitized country rock.

Quartz veinlets that in places contain calcite, epidote, and pyrite cut the dioritic rocks. Some of the quartz diorite and diorite contains hornblende-rich clots or aggregates of divergent hornblende' crystals. Planar structures are well developed throughout a large part of the dioritic unit and are manifested by fine-grained mafic inclusions and by the parallel orientations of mafic minerals. Linear internal structures are less conspicuous.

Criteria which aid in separating the dioritic unit and the quartz monzonite and granodiorite in the field are the darker appearance of the dioritic rocks owing to their abundant hornblende, their generally finer grained textures, commonly their finer grained inclusions, and the general dominance of hornblende over biotite in the quartz diorite and diorite. The quartz monzonite and granodiorite contain megascopically recognizable K-feldspar and more abundant quartz.

The quartz diorite and diorite are commonly hypidiomorphic granular, but a few of them are porphyritic. Most of the quartz diorite and diorite are similar in composition. Their principal difference is in quartz content, which ranges from less than 1 percent in some diorite to more than 20 percent in most of the quartz diorite. The plagioclase commonly is andesine or calcic oligoclase except where the rocks have been albitized. Hornblende is the dominant mafic mineral. Modal analyses of 12 thin sections of the dioritic rocks are shown in table 3 (Nos. 7–18). The results of semiquantitative spectrographic analyses and equivalent and chemical uranium analyses of a quartz diorite (No. 57AMK–25) and six albitized dioritic rocks (Nos. 56AMK–132, –143 and 57AMK–17, –19, –141, –143A) are shown in table 13.

Modal analyses for the dioritic rocks in terms of three end members, plagioclase, quartz, and K-feldspar, are shown on plate 2. Albite is included with the plagioclase, and the rocks that contain albite are shown by circled dots. The high content of mafic minerals in the dioritic rocks is not evident from plate 2, but it, as well as details of the mineralogy, can be ascertained by referring to table 3.

Chemical analyses, specific gravities (sp gr), and CIPW norms for four of the dioritic rocks are shown in table 4 (Nos. 1–4).

The norms of these rocks are shown in a ternary diagram in terms of the three constituents, plagioclase, including both albite and anorthite, orthoclase and quartz, in figure 4.

Sainsbury (1961) shows chemical analyses and CIPW norms for three samples of quartz diorite and diorite from the Craig C–2 quadrangle (fig. 1) about 50 miles north of Bokan Mountain. These rocks are chemically similar to the analyzed quartz diorites and diorites from the Bokan Mountain area, but they generally contain more quartz.

QUARTZ MONZONITE AND GRANODIORITE

DISTRIBUTION AND RELATION

The quartz monzonite and granodiorite unit is widely distributed, and along with dioritic rocks underlies most of the map area. Quartz monzonite and granodiorite are well exposed along the shorelines of many embayments in the area and constitute large parts of many mountainous masses.

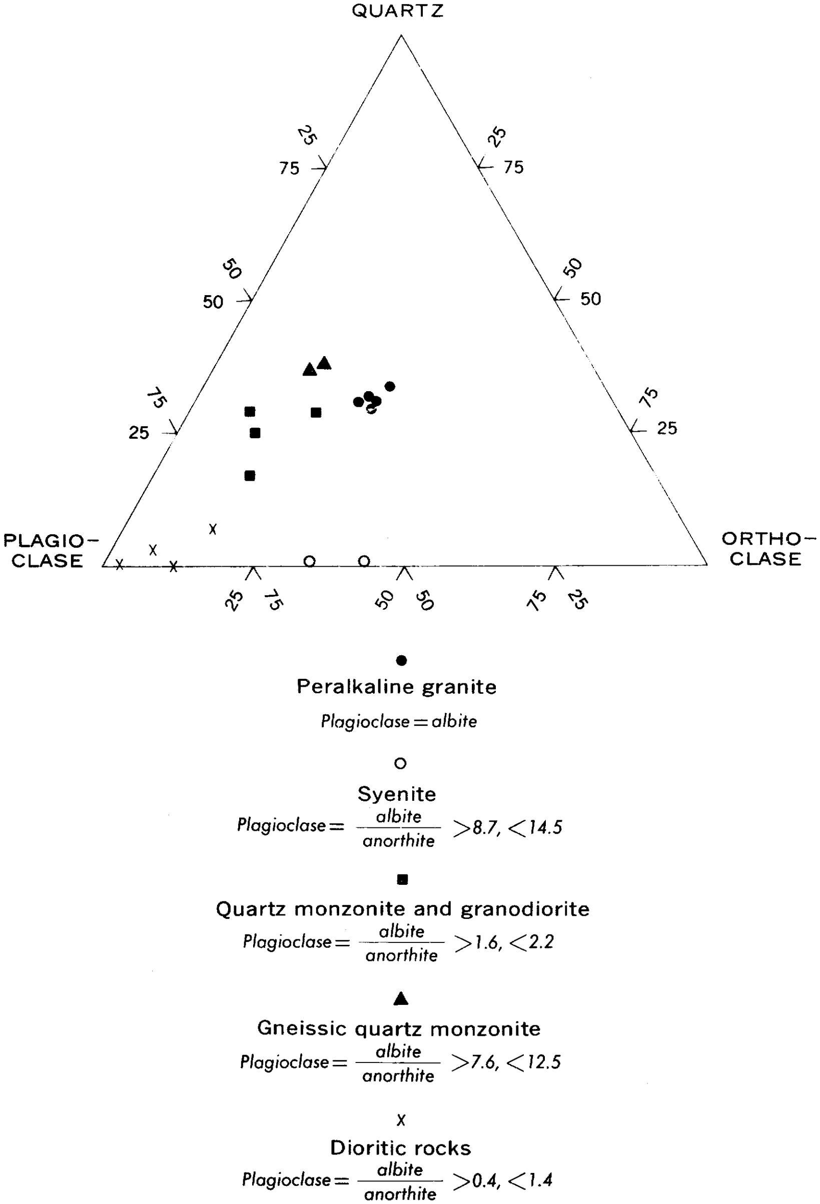

FIGURE 4.—Ternary diagram of the chemically analyzed plutonic rocks from the Bokan Mountain area (based on CIPW norms).

TABLE 4.—*Chemical analyses and norms of the plutonic rocks*

[Analysts, P. L. D. Elmore, S. D. Botts, H. H. Thomas, and M. D. Mack, U.S. Geol. Survey, 1958]

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Analyses (weight percent)																	
SiO_2	52.6	45.0	46.4	55.1	68.8	68.6	66.6	61.6	76.9	74.5	63.1	62.1	73.4	74.1	73.6	74.6	73.8
Al_2O_3	18.4	19.2	16.9	17.8	16.6	15.2	16.5	16.7	12.9	13.5	17.9	18.9	11.0	12.3	11.6	11.9	11.5
Fe_2O_3	3.2	5.8	4.1	2.7	1.0	1.5	1.4	1.9	.3	.1	1.3	1.0	3.6	1.5	2.1	1.2	2.6
FeO	4.9	6.8	7.2	5.2	1.7	1.8	1.9	3.0	.9	1.5	1.3	1.2	1.8	2.0	2.5	2.5	2.5
MgO	4.6	5.9	7.4	3.3	.92	1.4	1.2	2.6	.30	.76	.65	.42	<.05	<.05	<.05	.09	.08
CaO	9.5	10.2	11.5	6.1	3.6	3.5	4.6	5.9	.62	1.0	1.2	1.4	<.05	<.05	<.05	.27	.14
Na_2O	3.6	2.8	1.6	4.0	4.6	3.4	4.2	4.0	4.6	4.5	5.7	6.3	4.5	4.8	4.9	4.9	5.0
K_2O	.74	.42	1.1	1.9	1.5	3.2	2.1	2.3	2.8	2.5	6.7	5.3	4.6	4.7	4.5	4.1	4.2
H_2O	.94	2.1	2.0	1.9	.82	.92	.82	1.0	.52	.90	.58	.54	.35	.38	.37	.46	.31
TiO_2	.66	1.2	1.0	.98	.26	.32	.38	.54	.14	.20	.44	.16	.20	.15	.14	.12	.12
P_2O_5	.24	.23	.05	.35	.14	.10	.11	.17	.05	.02	.06	.06	.00	.00	.00	.01	.00
MnO	.17	.22	.22	.20	.12	.08	.07	.10	.02	.06	.08	.08	.05	.08	.10	.10	.10
CO_2	<.05	<.05	<.05	.36	<.05	<.05	<.05	<.05	<.05	.11	.90	1.4	.26	.29	.26	<.05	<.05
Sum	99.6	99.9	99.5	99.9	100.1	100.1	99.9	99.9	100.1	99.7	99.9	98.9	99.9	100.4	100.2	100.3	100.4
Specific gravity	2.86	2.92	2.98	2.82	2.70	2.70	2.72	2.76	2.63	2.62	2.64	2.58	--------	2.66	2.66	2.68	2.72
Norms (weight percent)																	
Q	2.22	--------	--------	5.40	26.82	26.46	22.56	13.56	37.14	34.20	1.38	1.32	30.66	27.60	27.36	28.38	28.14
or	4.45	2.22	6.67	11.12	8.90	18.90	12.23	13.34	16.68	15.01	39.48	31.14	27.24	27.80	26.69	24.46	25.02
ab	30.39	23.58	13.62	34.06	38.77	28.82	35.63	34.06	38.77	38.25	48.21	53.45	30.92	37.20	34.58	38.25	35.63
an	31.69	38.64	35.58	25.02	16.96	16.68	20.02	20.85	3.06	5.00	3.34	6.12	--------	--------	--------	--------	--------
C	--------	--------	--------	--------	1.22	--------	--------	--------	1.12	1.43	--------	.51	--------	--------	--------	--------	--------
di	11.96	8.96	17.24	2.26	--------	--------	1.57	5.95	--------	--------	1.33	--------	--------	--------	--------	1.24	.75
hy	12.02	4.55	10.93	13.14	4.28	5.22	3.95	6.84	1.99	4.14	1.63	2.42	1.55	3.27	4.59	4.27	4.01
ac	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	6.47	2.77	6.01	2.77	6.01
ol	--------	8.47	7.41	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------
il	1.37	2.28	1.98	1.98	.61	.61	.76	1.06	.30	.46	.76	.30	.46	.30	.30	.15	.15
mt	3.25	8.35	6.03	3.94	1.39	2.09	2.09	2.78	.46	.23	1.86	1.39	2.09	.70	--------	.46	.70
ap	.34	.34	--------	1.01	.34	.34	.34	.34	--------	--------	.34	.34	--------	--------	--------	--------	--------

1. Hornblende quartz diorite, 8,500 ft S. 22° E. of loading dock on West Arm of Kendrick Bay.
2. Hornblende diorite, 4,300 ft N. 27° W. of head of South Arm of Kendrick Bay.
3. Hornblende diorite, from an island in Kendrick Bay 14,000 ft S. 67° E. of loading dock on the West Arm of Kendrick Bay.
4. Hornblende quartz diorite, from an island 5,500 ft S. 77° E. of the head of Gardner Bay.
5. Biotite granodiorite, 13,000 ft S. 33° E. of the east end of Hessa Lake.
6. Quartz monzonite, west shore 5,000 ft N. 12° E. of the head of the South Arm of Kendrick Bay.
7. Hornblende granodiorite, from an island in Kendrick Bay 12,000 ft S. 54½° E. of loading dock on the West Arm of Kendrick Bay.
8. Biotite-hornblende granodiorite, from an island in Kendrick Bay 14,500 ft S. 60½° E. of loading dock on the West Arm of Kendrick Bay.
9. Gneissic quartz monzonite, east shore 11,600 ft N. 25° E. of the head of the South Arm of Kendrick Bay.
10. Gneissic quartz monzonite, on headland between the east shore of the South Arm of Kendrick Bay and Kendrick Bay.
11. Syenite, south shore of Stone Rock Bay.
12. Syenite, on headland between Stone Rock Bay and Mallard Bay.
13. Bokan Mountain granite, 650 ft S. 78° W. of Ross-Adams mine.
14. Bokan Mountain granite, 1,500 ft S. 88° W. of Bokan Mountain.
15. Bokan Mountain granite, 4,000 ft N. 10° W. of Bokan Mountain.
16. Bokan Mountain granite, 3,650 ft N. 40° W. of Bokan Mountain.
17. Bokan Mountain granite, 2,600 ft S. 87° E. of Bokan Mountain.

The quartz monzonite and granodiorite unit is divided into two parts, albitized quartz monzonite and granodiorite, which is mainly in the northwestern part of the area, as shown by an overlay pattern on plate 1, and unalbitized quartz monzonite and granodiorite, which is widely distributed elsewhere in the area. The albitized quartz monzonite and granodiorite is localized roughly concentrically about the boss of Bokan Mountain granite, from which it extends outward to unalbitized quartz monzonite and granodiorite and to albitized dioritic rock. Locally the albitized quartz monzonite and granodiorite intrude metavolcanic rocks and slate of probably Devonian age. Elsewhere these albitized rocks grade into unalbitized quartz monzonite and granodiorite or into albitized dioritic rocks. In places, apophyses of the albitized quartz monzonite and granodiorite penetrate the dioritic rocks.

The contact between the Bokan Mountain granite and the albitized quartz monzonite and granodiorite is generally obscured by alteration. It appears to be gradational and probably dips steeply. The arcuate trace of this contact around the peralkaline granite boss and the occurrence of pegmatite dikes and aplite dikes and the small masses genetically akin to the peralkaline granite, penetrating the albitized quartz monzonite and granodiorite, indicate that the granite is the younger of the two rocks.

The unalbitized quartz monzonite and granodiorite intrudes schist, gneiss, amphibolite, pyroxenite, and dioritic rocks. Contacts between unaltered quartz monzonite and granodiorite and the gneissic quartz monzonite, which are exposed on the Kendrick Islands, are gradational and nondiagnostic in determining the chronological sequence of the rocks. Most contacts between the quartz monzonite and granodiorite and the syenite, which are in the extreme southern part of the area, appear to be gradational, but syenite dikes locally penetrate quartz monzonite and establish syenite as the younger of the two rocks. Unalbitized quartz monzonite and granodiorite have been intruded by aplite south of the mouth of Mallard Bay forming fairly sharp and steep contacts.

Mafic dikes are more sparsely distributed in the quartz monzonite and granodiorite than they are in the dioritic rocks. A few pegmatite and aplite dikes, including some related to the peralkaline granite, cut the quartz monzonite and granodiorite.

PETROLOGY AND PETROGRAPHY

ALBITIZED QUARTZ MONZONITE AND GRANODIORITE

The albitized quartz monzonite and granodiorite is a light gray to white rock that is strongly altered and fractured and locally is silicified. Included with it are small amounts of albitized granite which were not mapped separately. Such outcrops are found near the contact with the peralkaline granite boss; a good example of this rock is well exposed along the upper part of the road to the Ross-Adams mine. This rock is believed to be a local K-feldspar-rich part of the larger mass of quartz monzonite and granodiorite. Planar and linear structures were not seen within any of these albitized rocks.

The albitized quartz monzonite and granodiorite commonly is medium grained or coarse medium grained with minor coarse- and fine-grained variants. It commonly is hypidiomorphic granular in texture, but cataclastic textures are moderately abundant, and porphyritic textures are uncommon. It consists mainly of quartz, albite, and K-feldspar; the other primary mineral is sparsely distributed biotite. These rocks generally contain subordinate amounts of epidote, calcite, pyrite, and chlorite and are cut by numerous veinlets that are quartz rich. Calcite veinlets locally cut the quartz-rich veinlets.

Alteration of the quartz monzonite and granodiorite consists chiefly of the albitization of plagioclase and local silicification. Both of these features are most intense near the peralkaline granite boss. The combined albite, K-feldspar, and quartz content of these rocks averages about 95 percent of their volume. The K-feldspar consists largely of anhedral microperthitic masses that surround and embay earlier grid-twinned K-feldspar and albite. The albite is most sodic near the Bokan Mountain granite, and its sodium content decreases nearly progressively outward from the peralkaline granite to the outer limits of albitization where oligoclase is the dominant plagioclase. The minor quantities of mafic minerals occur in fine-grained scaly aggregates near veinlets, which may indicate that they were formed by deuteric processes or by subsequent hydrothermal alteration.

Modal analyses of six thin sections of albitized quartz monzonite and granodiorite are shown in table 3 (Nos. 19–24). Modal analyses of the albitized quartz monzonite and granodiorite are shown in a ternary diagram on plate 2.

The results of semiquantitative spectrographic analyses and of equivalent and chemical uranium analyses of eight albitized quartz monzonites and granodiorites are shown in table 13 (Nos. 56AMK–88, –116, –124, –134, –138, –140, –151, and 57 AMK–80).

UNALBITIZED QUARTZ MONZONITE AND GRANODIORITE

The unalbitized quartz monzonite and granodiorite is a light-gray rock speckled with mafic minerals. Rocks of this unit consist chiefly of plagioclase with moderately abundant quartz and K-feldspar and sparse to fairly abundant biotite and hornblende. Rock types arranged in order of abundance and included in this unit are: hornblende granodiorite, biotite-hornblende granodiorite, leucrocratic granodiorite, biotite granodiorite, biotite-quartz monzonite, leucocratic quartz monzonite, and hornblende-quartz monzonite.

Planar features are moderately abundant, particularly near contacts with the dioritic rocks, where abundant elongated dioritic inclusions that are parallel highlight this structure. Linear structures are poorly developed but in some places alined hornblende crystals have been seen.

The unalbitized quartz monzonite and granodiorite is mainly hypidiomorphic-granular rock that is medium or coarse-medium grained. Its combined plagioclase-quartz-K-feldspar content ranges from 60 to 95 percent by volume, but commonly it is between 75 and 90 percent. The plagioclase ranges in composition from calcic andesine to sodic oligoclase, but most of it is between An_{35} and An_{25}, and it is normally zoned generally through about 5 or 10 percent An, but uncommonly through as much as 25 percent An. Besides being unalbitized, the quartz monzonite and granodiorite differ from the albitized varieties by generally containing more mafic minerals and fewer veinlets, by being much less altered, and by showing fewer cataclastic effects. Microscopic vermicular intergrowths between feldspar and quartz have developed in some of these rocks.

Modal analyses of 19 thin sections of the unalbitized quartz monzonites and granodiorites are shown on a ternary diagram on plate 2. Modal analyses of six thin sections of unalbitized quartz monzonite and granodiorite are shown in table 3 (Nos. 25–30). The chief differences between the albitized and unalbitized quartz monzonites and granodiorites are revealed by examining plate 2 and table 3. The results of semiquantitative spectrographic analyses and of equivalent and chemical uranium analyses of four unalbitized quartz monzonites and granodiorites are shown in table 13 (Nos. 57AMK–20, –62A, 57AMK–21, –34).

Chemical analyses and norms of four unalbitized quartz monzonites and granodiorites and their specific gravities (sp gr) are shown in table 4 (Nos. 5–8), and the major normative constituents are graphically represented in a ternary diagram on figure 4.

GNEISSIC QUARTZ MONZONITE

DISTRIBUTION AND RELATION

The gneissic quartz monzonite is well exposed on the headland between Kendrick Bay and Gardner Bay, near the mouth of the South Arm of Kendrick Bay, and on some of the Kendrick Islands.

To a large extent it is in contact with the Devonian schist, which it has invaded, forming steep commonly gradational and concordant contacts. Where the gneissic quartz monzonite has intruded the dioritic rocks, the contacts are also mainly steep and gradational.

The contact relations between the gneissic quartz monzonite and the quartz monzonite-granodiorite unit are difficult to interpret, but the gneissic quartz monzonite is probably the younger of the two rocks. Pegmatite dikes and andesitic dikes are sparsely distributed in the gneissic quartz monzonite.

PETROLOGY AND PETROGRAPHY

The gneissic quartz monzonite is a strongly foliated silica-rich rock with which subordinate amounts of silica-rich granodiorite are found. It is probably closely related to the albitized quartz monzonite-granodiorite, but differs from rocks of this unit by being strongly foliated, by generally containing more quartz, and by being coarser grained.

The characteristic gneissic texture results from the good alinement of biotite crystals, and this foliation is parallel to contacts between the gneissic quartz monzonite and adjacent rocks. The gneissic quartz monzonite resists erosion better than most other rocks in the area, and it constitutes several small nearshore islands and "rocks" south of the mouth of Kendrick Bay. The gneissic quartz monzonite is largely coarse- or coarse-medium-grained rock and is generally hypidiomorphic granular in texture. Like the albitized quartz monzonite-granodiorite this rock is characteristically light colored, shows abundant cataclastic effects, is cut by quartz veinlets, and contains abundant quartz, plagioclase, and K-feldspar.

Modal analyses of thin sections of two rocks representative of this unit, a gneissic granodiorite (No. 31) and a gneissic quartz monzonite (No. 32) are shown in table 3. A ternary diagram showing the results of modal analyses of these two thin sections is shown on plate 2. The results of semiquantitative spectrographic analyses and of equivalent and chemical uranium analyses of two gneissic quartz monzonites are shown in table 13 (Nos. 57AMK-56, -62). The results of chemical analyses of two gneissic quartz monzonites and their norms and specific gravities (sp gr) are shown in table 4 (Nos. 9, 10). The high SiO_2content and the low Fe_2O_3, FeO, MgO, and CaO contents are notable. The norms of the gneissic quartz monzonites, which are appreciably salic and have high contents of normative quartz and albite, are represented graphically in figure 4.

SYENITE

DISTRIBUTION AND RELATION

Syenite has been found only in the southern part of the area, principally near Stone Rock Bay. The largest mass trends northwestward from the headland north of Stone Rock Bay to near the head of McLean Arm. Syenite constitutes most of the islands in and near Stone Rock Bay, and it forms two dikelike bodies that extend westward from the southern shores of Stone Rock Bay.

The syenite intrudes the pyroxenite, the dioritic rocks, and the quartz monzonite-granodiorite. Its contacts with these rocks are generally poorly exposed, but the intrusive relations are established by syenite dikes cutting the other rocks and by local blocky dioritic inclusions in the syenite. Syenite is in fault contact with gabbro near the head of McLean Arm. Contacts between the syenite and aplite are poorly exposed but some aplitic masses appear to penetrate the syenite. In a few places the syenite is cut by mafic dikes and by quartz-calcite veins.

PETROLOGY AND PETROGRAPHY

The syenite is typically a leucocratic rock that is pink or white and generally is blocky and massive appearing with local poorly developed planar structure. Some of the syenite grades into monzonite—a gradation that is imperceptible in the field—and the monzonite is mapped with the syenite. The monzonite is largely restricted to the largest syenite mass, particularly near the Polson and Ickis copper prospects. The syenite is characterized by abundant K-feldspar, which commonly imparts a pinkish hue to the rock, and by a general uniformity in appearance.

The syenite is mainly a medium-grained rock that is somewhat finer grained in apophyses and dikes. It is xenomorphic granular or hypidiomorphic granular in texture. Trachytoid textures are developed in some, and a few of the syenites contain granulated minerals and quartz and calcite veinlets. The dominant rock is a syenite, which has K-feldspar as its dominant constituent. The K-feldspar commonly is microperthitic and contains abundant albite or sodian adularia(?). It surrounds and replaces plagioclase. Excluding the albite of the microperthite, most of the plagioclase is oligoclase, or in the more monzonitic varieties, sodic andesine. Locally the syenite contains garnet which has an index of refraction of 1.875 and a specific gravity of 3.75±0.03. These properties place it near the andradite end member of the grosularite-andradite series (Winchell and Winchell, 1951, p. 485). Its unit cell dimension $A_0 = 12.06 \pm .02$A. An aegirine-augite, which is found in some of the syenite, forms zoned crystals that are pleochroic with X and Y being greenish brown and Z, yellowish green. Its 2V is (+) 68° in the inner zone of the crystals and (+) 58° near rims. The extension angle $Z \wedge C$ is about 56°.

Modal analyses of two thin sections of syenite are shown in table 3 (Nos. 33, 34) and are depicted graphically on plate 2. The results of semiquantitative spectrographic analyses and of equivalent and chemical uranium analyses of two syenite samples are shown in table 13 (Nos. 57 AM*K*–126, –131 B). Notable results of these analyses are the high potassium content, the moderately abundant barium which has probably proxied for potassium in some of the K-feldspar, and the presence of minor amounts of lanthanum, cerium, and neodymium.

Chemical analyses of two syenite specimens and their norms and specific gravities are shown in table 4 (Nos. 11, 12). The high Na_2O content of the syenite indicates that much albite or sodian adularia(?) is included in the microperthitic intergrowths. The composition of the syenite is similar to that of the average alkali syenite, as compiled by Nockolds (1954, p. 1016, table 3), differing chiefly by containing smaller amounts of the iron oxides and lime. The CO_2 content of the Bokan Mountain area syenite is attributed to calcite from veinlets. CO_2 was not reported in Nockold's analyses. The CO_2 is considered to be a constituent of secondary calcite and is not shown in a normative mineral.

The composition of the syenite based on the normative plagioclase, orthoclase, and quartz is graphically represented on a ternary diagram in figure 4. Further indications of substantial amounts of albite or sodian adularia(?) in the syenite are evident from examining this diagram.

BOKAN MOUNTAIN GRANITE

NAME, DISTRIBUTION, AND RELATION

The rock that constitutes the small stock or boss centered near Bokan Mountain is, following the nomenclature of Shand (1951, p. 51), a peralkaline granite and is here named the Bokan Mountain granite. This rock has been briefly described by MacKevett (1957b, 1957c). The boss is approximately 3 square miles in area and crudely circular in outline.

The Bokan Mountain granite intrudes slate, albitized quartz monzonite, and albitized quartz diorite. Small irregular masses of aplite cut the peralkaline granite near the margin of the boss. Small pegmatite and aplite dikes, genetically related to the peralkaline granite, are fairly abundant, particularly near the margin of the boss, and some of them cut the adjacent country rock.

Sparsely distributed small andesitic dikes apparently cut the peralkaline granite.

PETROLOGY AND PETROGRAPHY

The Bokan Mountain granite is an uncommon rock and similar rocks are unknown from southeastern Alaska. Most of the known riebeckite- and acmite-bearing granite in the world has been well, perhaps disproportionately, studied because of its rarity and its petrologic implications. Besides being an uncommon rock, the peralkaline granite is of interest because almost all of the uranium-thorium deposits in the area are believed to the genetically affiliated with it. The peralkaline granite is white to light gray and commonly speckled with about 10 percent of mafic minerals. Its dominant rock types are riebeckite- and (or) acmite-bearing peralkaline granite that is silica rich. The peralkaline granite commonly forms bold bare outcrops, as shown in figure 5. Exposures of the peralkaline granite are confined to relatively high ground. On some of the gentler flanks of Bokan Mountain, the bedrock is mantled by residual quartz phenocrysts and lesser amounts of riebeckite crys-

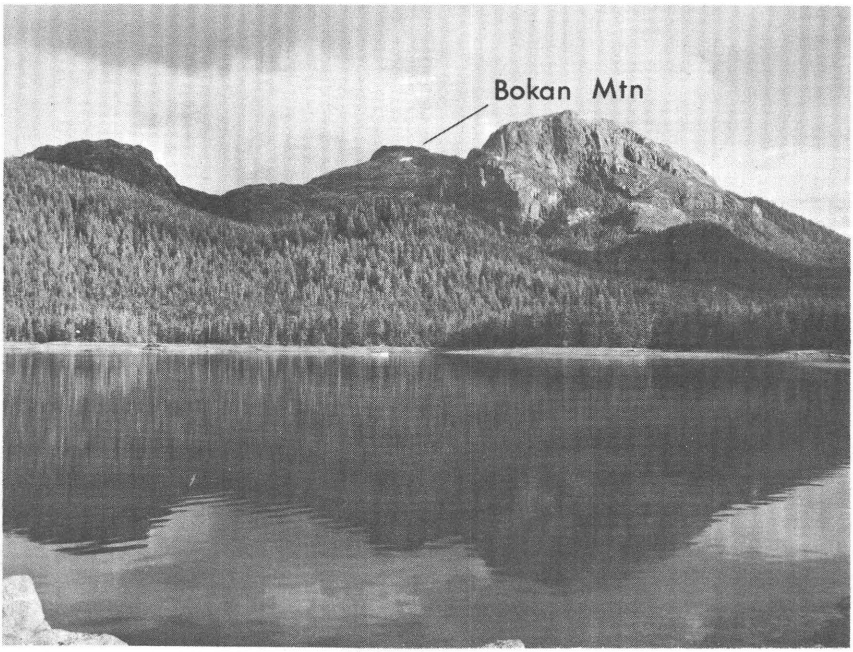

FIGURE 5.—View of Bokan Mountain from the South Arm of Moira Sound. Camera faces south. The bold, clifflike exposures are typical of areas underlain by the peralkaline granite.

tals. The Bokan Mountain granite lacks linear or planar internal structures, but it commonly shows local cataclastic effects. It is cut by numerous joints and by strong faults.

The Bokan Mountain granite is characterized by diverse grain sizes and textures, a high quartz content, and sodium-bearing mafic minerals. It ranges from fine to coarse grained, and its textures include porphyritic, seriate porphyritic, protoclastic, cataclastic, hypidiomorphic granular, and xenomorphic granular. Porphyritic and cataclastic textures prevail. The porphyritic textures are commonly shown by euhedral quartz phenocrysts that range from 5 to 20 mm in length embedded in a fine- or medium-grained groundmass and the cataclastic textures by granulated quartz or by fractured minerals, chiefly quartz and feldspar. Some of the fractured quartz phenocrysts are locally cut by younger quartz and feldspar. Some of the fine-grained assemblages are partly granulated. Modal analyses of five thin sections of the Bokan Mountain granite are shown in table 3 (Nos. 35–39).

The euhedral quartz phenocrysts have well-developed prismatic and rhombohedral faces and the external symmetry of beta (high) quartz. The quartz was formed during at least two stages, and quartz veins transect the older quartz and the other minerals. The quartz contains fairly abundant inclusions, comprising liquid, gaseous, and solid phases, and W. W. Virgin, Jr. (written communication, 1959) attempted to determine its temperature of formation by geothermometric means. The only inclusions that were amenable to geothermometric determinations represent secondary inclusions that were formed during or after the deformation of the granite. Their vapor phases disappeared between 160° and 165°C. and adding an assumed pressure correction factor equivalent to about 20° C, the indicated temperature of formation was about 180° or 185°C.

The K-feldspar also occurs in two stages. Grid-twinned microcline crystals that are fine- or medium-grained crystallized during the early stage. This microcline is embayed by large irregular microperthitic masses, which formed during the later stage and which constitute most of the K-feldspar (fig. 6). Sodian adularia is a constituent of some of these masses.

The formation of the two stages of quartz and K-feldspar pose interesting problems. In this respect the Bokan Mountain granite is similar to rapakivi granite, which commonly contains an early stage of chiefly euhedral quartz and K-feldspar and a late stage in which these minerals are anhedral (Savolahti, 1956, p. 83). Its lack of mica and the low water content may indicate that the Bokan Mountain granite crystallized from a relatively dry magma.

The early microcline probably was partly euhedral, but the subsequent microperthitic K-feldspar has embayed it irregularly.

Tuttle and Bowen (1958, p. 97, 98) offer a plausible explanation for the development of two stages of quartz and K-feldspar in the rapakivi granite. They conceive of vapor pressures in a hydrous crystallizing granite eventually exceeding those which the overburden could withstand, causing the fracturing of the roof and an accompanying sudden release of pressure. This process would lead to rapid crystallization and the probable development of many new centers of crystallization from which the second generation quartz and K-feldspar could emanate. A similar process may well have taken place during the evolution of the Bokan Mountain granite.

Regardless of whatever mechanisms occurred, the Bokan Mountain granite apparently has a complex history, and its initial composition was such that the first major minerals to crystallize were quartz and grid-twinned K-feldspar.

The albite that occurs in discrete crystals is little altered and finely albite twinned. Its lack of alteration, generally euhedral crystals, and distribution indicate that is was formed fairly late in

FIGURE 6.—Sodium-rich microperthite (P) embaying older grid-twinned K-feldspar (K); ab is albite, and Q is quartz. Partly crossed nicols (× 25).

the sequence of crystallization but probably prior to the late-stage quartz.

Riebeckite and acmite together form about 10 percent of the granite, but local segregations contain as much as about 40 percent of these minerals. They commonly occur in prismatic crystals as much as 16 mm long. Generally the two minerals are intergrown (fig. 7), but in some specimens only one of them is present. Similar relations between riebeckite and aegirine (acmite) in the riebeckite granite of northern Nigeria and their chemical and mineralogical properties are well described by Jacobson and others (1958, p. 16, 18, 19). Small riebeckite and (or) acmite crystals in places are included in the quartz of the Bokan Mountain granite. Some of the acmite crystals are speckled with hematite, which apparently has exsolved from them.

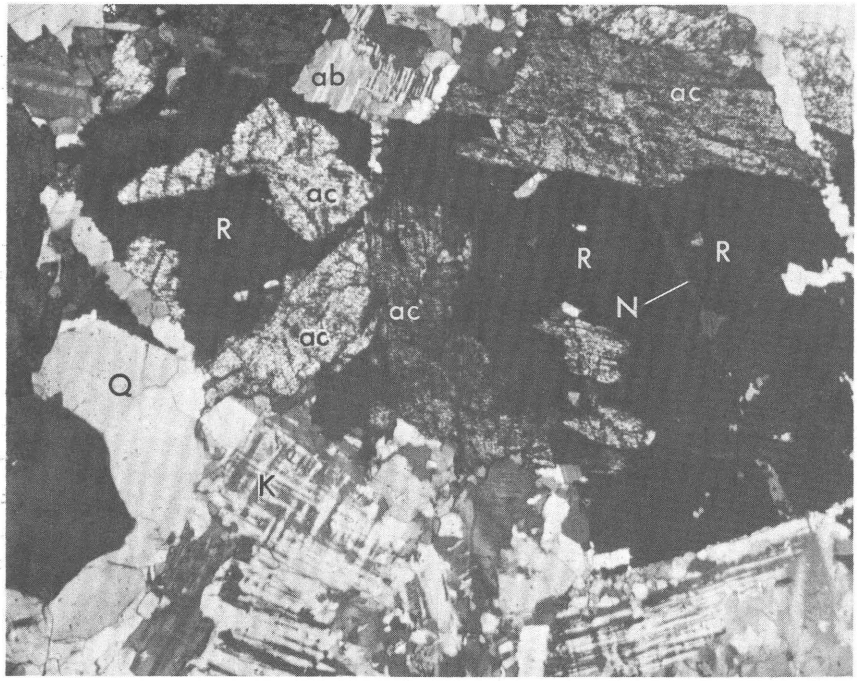

FIGURE 7.—Riebeckite (R) and acmite (ac) in peralkaline granite. The other minerals in the field are grid-twinned K-feldspar (K), albite (ab), quartz (Q), and montronite (?) (N), in a veinlet. Partly crossed nicols (× 16).

A chemical analysis, atomic proportions, X-ray powder diffraction data, and the optical properties of the riebeckite from the Bokan Mountain granite are shown in table 5.

TABLE 5.—*Chemical analysis, atomic proportions, X-ray powder diffraction data, and optical properties of riebeckite from the Bokan Mountain granite*

[Chemical analysis by S. M. Berthold; other determinations by R. G. Coleman, both of U.S. Geol. Survey.]

Chemical analysis					X-ray powder diffraction data	
	Weight percent	Number of atoms			d observed (A)	I
SiO_2	51.34	7.92	0.08	8.00	8.50	100
Al_2O_3	1.48	.27	.19		4.52	20
TiO_2	.68	.08		1.84	4.04	5
Fe_2O_3	13.37	1.57			3.88	5
FeO	21.26	2.77			3.41	10
MnO	.74	.10		2.91	3.27	10
MgO	.18	.04			3.14	70
CaO	.54	.09			2.98	5
Na_2O	7.98	2.41		2.80	2.82	20
K_2O	1.62	.32			2.72	40
H_2O^+	.90	.93			2.60	10
H_2O^-	.00	----		1.79	2.54	5
F	1.74	.86			2.39	5
					2.34	10
					2.18	10
					2.075	2
					2.040	5
					1.721	2
					1.692	2
					1.658	10
					1.636	2
					1.615	5
					1.590	2
					1.539	3
					1.438	10
	101.83					
O for F	.73					
	101.10					

$(Na, Ca, K)_{2.80}(Fe^{+2}, Mn, Mg)_{2.91}(Fe^{+3}, Al, Ti)_{1.84}Si_{8.0}O_{22}(OH,F)_{1.79}$

$\alpha = 1.687 \pm 0.003$ X = dark blue
$\beta = 1.692 \pm 0.003$ Y = light green yellow
$\gamma = 1.699 \pm 0.003$ Z = medium purplish blue
2V = large (+) $r > v$
$X \wedge c = 6°–8°$ optic axial plane perpendicular to (010)
$Density_{25°C} = 3.37 \pm 0.02$

The most notable minor accessory minerals in the Bokan Mountain granite are zircon, xenotime, fluorite, uranothorite, and cordierite. Zircon is generally the most abundant of these, and some of it is polysynthetically twinned. Xenotime and uranothorite form small euhedral crystals that are sparsely disseminated in the granite; the uranothorite is altered to a metamict state. Fluorite and cordierite are mainly in interstitial anhedral crystals. Small amounts of fluorite are widely distributed throughout the granite, but cordierite is an uncommon accessory, which is confined to marginal zones of the granite, and is probably an endothermic mineral.

The results of modal analyses of 26 thin sections of the Bokan Mountain granite are shown on a ternary diagram on plate 2. In this figure the corners of the triangle represent albite, K-feldspar and sodian adularia, and quartz. The K-feldspar contains moderately abundant microperthite and some sodian adularia, which results in an Na_2O content greater than the modal analyses that plate 2 indicates. A more accurate concept of the chemical composition of these rocks can be obtained from their chemical analyses and their norms (table 4, Nos. 13–17).

The peralkaline granite from near the Ross-Adams lode, from approximately the area included in figure 16, commonly contains less quartz than elsewhere. Specimen modes are represented by the circled dots on plate 2. Semiquantitative spectrographic analyses and equivalent and chemical uranium analyses of seven samples of the peralkaline granite are shown in table 13 (Nos. 56AMK–1, –159, –168, –219, –225, –233, –234). These analyses show the dominance of potassium and sodium over calcium and magnesium and the presence of noteworthy amounts of minor elements including cerium, yttrium, lanthanum, niobium, neodymium, uranium, thorium, and erbium.

The most radioactive intrusive rocks that are described by Larsen and Phair (1955, p. 86, 87) in their survey of the distribution of uranium and thorium in igneous rocks are sodium-rich late-stage granitic rocks, which are similar in many respects to the Bokan Mountain granite. Like the Bokan Mountain granite, these highly radioactive rocks are typically unfoliated and are believed to have been intruded at shallow depths subsequent to the major orogenic activity.

The Bokan Mountain granite is similar to the riebeckite granite of northern Nigeria, which has been extensively studied (Jacobson, and others, 1958). This riebeckite granite closely resembles the Bokan Mountain granite in chemical and mineralogical composition, although some of its common accessory minerals such as cryolite and pyrochlore were not found in the Bokan Mountain granite. In common with the Bokan Mountain granite, the Nigerian riebeckite granite contains accessory thorite and fluorite.

The peralkaline nature of the Bokan Mountain granite is manifested by the presence of normative acmite, indicating an excess of the molecular percentages of Na_2O plus K_2O over Al_2O_3. Further evidence that sodium is an abundant constituent of the microperthite, which was included in the modal K-feldspar, is afforded by the high normative albite content.

A ternary diagram based on the norms of the five chemically analyzed peralkaline granites is shown in figure 2.

AGE AND PROBABLE GENESIS OF THE PLUTONIC ROCKS

Field criteria for dating rocks in the Bokan Mountain area are meager. The plutonic rocks intrude metasedimentary and metavolcanic rocks of probable Devonian age and are cut by andesite and other dikes that are questionably Tertiary in age.

The age of a sample of hornblende quartz diorite from the Craig C-2 quadrangle (fig. 1), collected by C. L. Sainsbury, was determined by the lead-alpha method to be 103 million years, or within the Cretaceous period (Matzko and others, 1958, p. 532). Possibly most of the Bokan Mountain area batholithic rocks were formed during approximately the same time interval as similar rocks in the Craig C-2 quadrangle and, likewise, are Cretaceous in age, but basing the age of a plutonic sequence on one isotopic age determination from rocks of a nearby region is of a questionable validity.

The Bokan Mountain area and the Craig C-2 quadrangle are separated by about 50 miles of terrain that is largely underlain by sedimentary and volcanic rocks (Buddington and Chapin, 1929, pl. 1), and the plutonic rocks of the two areas are possibly unrelated. The Bokan Mountain plutonic rocks could be as old as late Paleozoic or as young as early Tertiary. In this report they are considered to be Cretaceous(?),[1] or in the case of the Bokan Mountain granite, Cretaceous(?)[1] and Tertiary(?).

With the probable exceptions of the pyroxenite, syenite, and monzonite, the plutonic rocks of the Bokan Mountain area are believed to be consanguineous. The plutonic sequence probably evolved largely through processes of fractional crystallization which resulted in the early crystallization of the more mafic rocks, the subsequent formation of the dominant plutonic rocks, and ultimately the crystallization of the late-stage partly felsic phases that were locally enriched in minor elements of the residual magmatic system. The crystallization sequence of the major plutonic rocks may be inferred from figure 4 by the crude linear arrangement of points extending from those representing the older dioritic rocks, through those of the granodiorite and quartz monzonite, to those representing the younger peralkaline granite.

The pyroxenite is probably the oldest plutonic rock in the area. It is probably a pretectonic or early syntectonic intrusive and may have played a role in the orogenic cycle similar to the alpine-type serpentinized peridotite described by Hess (1955, p. 394).

The gabbro, which is largely restricted to border zones of the dioritic rocks, probably formed during an early stage of the main

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[1] On the figures and plates, the query after Cretaceous was omitted; the illustrations were prepared before more recent data led to a questioning of the Cretaceous age.

sequence of crystallization. Its formation was closely followed by the dioritic rocks and then granodiorite and quartz monzonite. The lighter colored phases of granodiorite and quartz monzonite, which are largely restricted to regions near the peralkaline granite boss and are largely albitized, are probably slightly younger than the main mass of granodiorite and quartz monzonite.

The gneissic quartz monzonite apparently was derived from a silica-rich magma, probably a part of the same magma that formed the chiefly leucocratic albitized quartz monzonite and granodiorite. Its gneissic texture is mainly a primary feature that developed during its formation, but it has been locally intensified by subsequent cataclastic effects.

The syenite apparently crystallized late in the plutonic sequence. Figure 4 indicates that the syenite deviates from the postulated evolutionary sequence of the plutonic rocks and that its lineage is obscure. Probably the syenite formed from small isolated magma reservoirs that were contaminated by reactions with the host rocks.

The Bokan Mountain granite is believed to represent a late stage of the fractionated residual magma. Tuttle and Bowen (1958, p. 87–89) present evidence for the continuous solubility relation between water and peralkaline granite magma, or for the continuous gradation from magma to hydrothermal solutions in the system $Na_2O \cdot K_2O \cdot Al_2O_3 \cdot SiO_2 \cdot H_2O$. Probably both magmatic and hydrothermal stages were involved in the genesis of the peralkaline granite, the hydrothermal stage being represented by veinlets, the introduction of some late-stage minerals, local concentrations of uncommon elements, and some pegmatitic and aplitic phases.

HYPABYSSAL ROCKS

Hypabyssal rocks are widespread throughout the area and are discussed under three headings, aplite, pegmatite, and andesite and other dikes. Most of the aplite and pegmatite dikes are genetically related to the peralkaline granite, but less extensive earlier phases of aplite and pegmatite are probably related to the quartz monzonite and granodiorite. The andesite and other dikes constitute an abundant and complex group of dikes that include andesite and dacite and subordinate amounts of lamprophyre, quartz latite, rhyolite, and diabase. A few of the dikes, particularly some aplites and pegmatites, are of potential economic interest because they contain uranium, thorium, zirconium, niobium, or rare earths.

The aplites probably formed during two or three different intervals. They, and also the pegmatites, are believed to represent end products in the fractionation sequence and to have crystallized from a mobile fluid rich in volatiles. The oldest aplites are those that form the few small dikes in quartz monzonite and granodiorite. They probably crystallized from small reservoirs of residual fluid that developed from local centers of crystallization in the quartz monzonite and granodiorite. The youngest of these aplites cut the syenite and probably represent end stages in the crystallization of the gneissic or leucocratic quartz monzonite. The aplites in and near the peralkaline granite boss developed in a similar fashion from the residual fluid of the peralkaline granite magma. The high content of uncommon constituents in the peralkaline granite magma enhanced the formation of proportionately greater amounts of aplite and pegmatite than were formed from the other magmatic reservoirs.

The pegmatites probably originated during two sepatate intervals. Those related to the quartz monzonite probably crystallized during late stages of crystallization from small local reservoirs of quartz monzonite magma. Subsequently the pegmatites related to the peralkaline granite were derived from volatile-rich end stages of the peralkaline granite magma probably during Late Cretaceous or early Tertiary time.

According to Buddington and Chapin (1929, p. 223–226) pegmatites are locally abundant throughout southeastern Alaska, and they are present near the borders of most stocks on the Alexander Archipelago. Sainsbury (1957) has described mica-bearing pegmatites from the southern part of Baranof Island and from near Sitklan passage, close to the international border south of Ketchikan.

Several of the uncommon minerals in the pegmatites associated with the peralkaline granite have been reported from the rare earth carbonate veins and the radioactive carbonate hematite veins near Salmon Bay on the north part of Prince of Wales Island (Houston and others, 1958, p. 10, 11).

Rare-earth-bearing pegmatites are known from numerous localities in the world. Among their most notable occurrences are the aegerine (acmite) pegmatites of the Kola Peninsula, U.S.S.R. (Turner and Verhoogen, 1951, p. 339) and the rare-earth pegmatites of central Texas and on the island of Honshu (Mason, 1958, p. 137).

The history of the andesite and other dikes is complex, involving several periods of intrusion several lithologic types, and, for many of the dikes, modifications by subsequent hydrothermal solutions. It has been only generally deciphered. Probably most of the dikes formed during early Tertiary time during a span that included several intervals of dike emplacement. The abundance of andesite and other dikes in the dioritic rocks may reflect a major period of dike formation shortly after the solidification of the diorites and quartz diorites probably during Cretaceous time. Or, more likely, the advent of large-scale dike emplacement took place much later and many of the dikes were preferentially localized by more favorable physical properties of the diorite and quartz diorite. The few dikes that cut the peralkaline granite are probably among the youngest dikes in the area. According to C. L. Sainsbury (oral communication, 1959) diabase dikes are common throughout southeastern Alaska, and they are younger than the andesitic dikes.

Dikes that are similar to the andesite and other dikes are widespread in southeastern Alaska (Buddington and Chapin, 1929, p. 229–312). They have been described from the Kasaan Peninsula (Wright and Paige, 1908, p. 102); and by Warner and others, 1961; from the Craig C–2 quadrangle (Sainsbury, 1961); near Copper Mountain (Wright, 1915, p. 41–43); from the Jumbo Basin (Kennedy, 1953, p. 12); and from the northern part of Prince of Wales Island (Houston and others 1958, p.7).

APLITE

DISTRIBUTION AND RELATION

The aplite intrusives are divisible into two types, those that are genetically related to the peralkaline granite, and older aplite dikes believed to be related to the quartz monzonite-granodiorite unit. Most aplites are of the younger type and occur as dikes or irregular masses in or near the peralkaline granite boss (pl. 1). Many aplites contain pegmatitic parts such as pods and lenses of coarse-grained quartz, and some occur as minor zones within pegmatite dikes. Some of the aplite masses contain subordinate alaskite facies.

Aplitic masses related to the peralkaline granite and including subordinate alaskite, crop out near the margins of the peralkaline granite boss east of the Ross-Adams mine and near the northwest margin of the boss (pl. 1). At the latter locality a dikelike body of aplite about 5,000 feet long and between 100 and 250 feet thick transects peralkaline granite, albitized quartz monzonite, and slate. Three small enclaves of this mass are also exposed within the slate. Many aplite dikes cut the Bokan Mountain granite, and most of these strike northwest and dip steeply. They are as much as 1,000 feet long and range from a few inches to about 10 feet in thickness.

The aplite that is related to the quartz monzonite or granodiorite forms a few small dikes in the southern part of the area and aplite-alaskite masses near the entrance to Mallard Bay and at Stone Rock Bay. The largest of these masses, which appears to be wedge shaped and about 2,000 feet long and 1,000 feet in maximum thickness, penetrates syenite and quartz monzonite. The other mass forms a small plug that intrudes syenite.

PETROLOGY AND PETROGRAPHY

The aplites are white to light-gray rocks, and locally the weathered surfaces are light brown. They are quartz rich and fairly resistant to erosion. Besides quartz, the minerals megascopically visible are K-feldspar, minor amounts of biotite, and in some specimens pyrite, in places altered to limonite. A few of the aplites contain minor amounts of riebeckite and fluorite. The aplites lack planar or linear internal structures, and except where they merge into typical pegmatites or contain pods of coarse-grained pegmatitic quartz, they appear to be homogeneous.

The aplites are largely fine-grained xenomorphic-granular rocks, but their minor alaskitic parts are medium grained with hypidiomorphic granular textures. Uncommonly they contain small-scale cataclastic textures that are indicated chiefly by granulated and fractured quartz. The aplites are mainly granite in composition, but they contain subordinate amounts of quartz monzonite. The aplites contain more K-feldspar than plagioclase, and the ones related to the peralkaline granite are albite bearing.

Plate 2 shows modal analyses of five aplites. The aplite dikes that are related to the peralkaline granite have a relatively high content of minor elements, largely rare earths. In some of these dikes the content of minor elements seems to be further enriched by hydrothermal alteration. Such altered dikes contain minor impregnations of pyrite and its alteration products and clay minerals. Analyses of a sample of altered aplite are shown in table 14.

PEGMATITE

DISTRIBUTION AND RELATION

The pegmatite dikes are of two different ages and genetic derivations. The older ones make up a subordinate group that is probably affiliated with the quartz monzonite-granodiorite. Most of these have intruded dioritic rocks, but a few are found within quartz monzonite. Most of the pegmatites are related to the peralkaline granite, in which most of them are found, although some intrude the adjacent rock. These younger pegmatites are the sites for most of the uranium-thorium prospects and have been well exposed in many of the prospect pits and trenches.

The pegmatite dikes range from a few inches to 4(?) feet in thickness and are traceable for distances of a few to 3,000 feet. The typical pegmatite is from 1–2 feet thick and is exposed over lengths less than 200 feet. A few of the pegmatites are in the form of small pods or lenticular masses. Minor dike swarms of pegmatite in which all of the bodies are crudely parallel to one another have been found locally within the peralkaline granite boss. Most however, have diverse strikes and dips.

The older pegmatites probably were derived from end stage fluids at local centers of crystallization in the quartz monzonite. These sparsely distributed pegmatites cut the quartz monzonite and granodiorite and the dioritic rocks, and in a few places they are cut by fine-grained andesitic dikes.

Some pegmatites are closely associated with aplite, and intergradations between the two rock types are common.

The largest pegmatite dike in the area cuts dioritic rocks east of the mouth of the South Arm of Kendrick Bay (pl. 1). Other pegmatite dikes that were probably derived from quartz monzonite residuum occur near Gardner Bay, where they contain a few uranium-thorium prospects, along the south shore of McLean Arm, and at scattered localities near Kendrick Bay (pl. 1).

PETROLOGY AND PETROGRAPHY

The pegmatites are light-colored rocks consisting largely of quartz and perthite, and they are characterized by diversities in texture and by the prevalence of very coarse grained crystals. Most of them are unzoned, but some have aplitic or medium-grained quartz-feldspar border zones and very coarse grained quartz-rich cores. Pegmatite dikes consisting of veinlike quartz masses are widely distributed throughout the peralkaline granite boss. These dikes show a close spatial relation with other pegmatites, and they are believed to have originated from silica-rich pegmatitic phases.

The pegmatites associated with the quartz monzonite-granodiorite contain crystals of pink perthite as much as 3 inches across, abundant quartz, and minor amounts of biotite, oligoclase, magnetite, and black tourmaline. Radioactivity anomalies are sparsely distributed in these pegmatites and are caused by emanations from widely scattered "radioactive blacks," complex uranium- or thorium-bearing minerals that are black or dark brown.

The essential minerals in the peralkaline granite pegmatites are quartz and perthite. Other minerals that are commonly visible megascopically include albite, hematite, fluorite, and magnetite; somewhat less common minerals found in some of them include biotite, riebeckite, acmite, pyrite, sphene, and zircon. Their anomalous radioactivity is due to an array of fine-grained uncommon minerals that are rich in minor elements. Those that have been identified are uranothorite, uranoan thorianite, uraninite, xenotime, bastnaesite(?) ellsworthite, parisite, and brannerite. The brannerite was identified by J. J. Matzko (written communication, 1956). Near the radioactive minerals, quartz is commonly clouded and gray and the fluorite is a deep purple.

Analyses of five pegmatite samples are shown in table 14. Samples 56AMK–158, –217, and –227 are from pegmatites related to the peralkaline granite, and several of these represent iron-rich pegmatites that have been hydrothermally altered. Some minor elements were undoubtedly added by the hydrothermal processes, as indicated by their general greater abundance in the altered pegmatites, but most constituent minor elements are believed to have entered into minerals of the pegmatite phase. The last two samples (Nos. 57AMK–66A and –104) are from pegmatites affiliated with the quartz monzonite. Representative samples of pegmatite are difficult to obtain, but the results shown in table 14 are at least qualitatively useful. They show the abundance of many minor elements, chiefly rare earths, in the pegmatites related to the peralkaline granite. Other notable features of these pegmatites are their high zirconium content, reflected by abundant zircon, and the occurrences of significant quantities of thorium, and to a lesser extent of uranium in a few of them. Conversely, the two pegmatites related to the quartz monzonite that were analyzed are deficient in uncommon elements.

ANDESITE AND OTHER DIKES

DISTRIBUTION AND RELATION

The wide variety of other dikes have been placed together in a single category. These range in composition from diabase to rhyolite, but most by far are either andesite or dacite. In mapping they have been separated into the following subgroups: andesite and dacite with subordinate lamprophyre, rhyolite and quartz latite, and diabase. These dikes are from a few inches to 40 feet in thickness and probably extend for several hundred or several thousand feet along their strike, but tracing them for any distance is generally precluded by the cover of soil, forest, or muskeg. They are well exposed for short distances at many places along the shorelines; here a few can be seen to end by "horsetailing" into numerous very thin branches, whereas some others gradually diminish in thickness and pinch out. The dikes formed during at least two different intervals as illustrated by figure 8, which shows steep dacite dikes cutting an andesite dike.

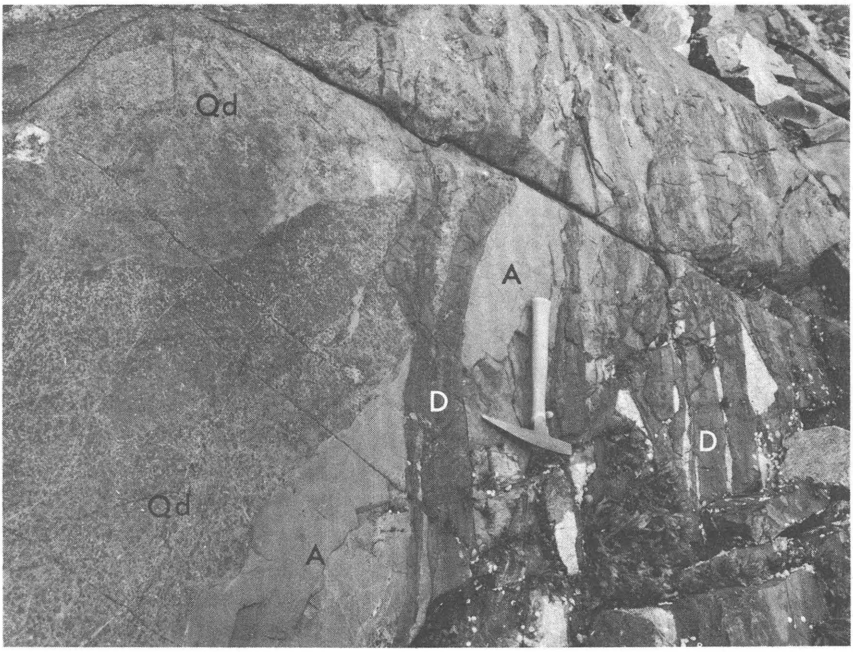

FIGURE 8.—Dacite dikes (D) cutting an andesite dike (A) near the west end of Kendrick Bay. The host rock is quartz diorite (Qd).

More than 80 percent of the dikes dip between 70° and vertical. The strikes of the steep andesite and similar dikes are shown diagrammatically in figures 9 and 10. Figure 9 represents 106 dikes from the northwestern part of the area, that part of the area west of the mouth of the West Arm of Kendrick Bay and north of parallel 54°52′30″. The 322 dikes that form the basis for figure 10 are from all other parts of the area.

The steep dikes from the northwestern part of the area (fig. 9) are roughly oriented into two conjugate systems. The sets of the first system strike N. 30°–50° W. and N. 50°–70° E., and those of the second system, which are better developed, strike N. 60°–70° W. and N. 30°–40° E. These relations probably indicate that the dikes in the northwestern part of the area largely occupied prexisting fractures. This belief is supported by the extensive development of fractures in the northwestern part of the area and by outcrops that show unfaulted dikes occupying ancient fault zones.

Throughout most of the area the strikes of the steep fine-grained dikes are largely in the N. 20°–40° W. sector (fig. 10). Some of these dikes were probably emplaced by a dilation or wedging mechanism in the manner described by Anderson (1951, p. 24–26).

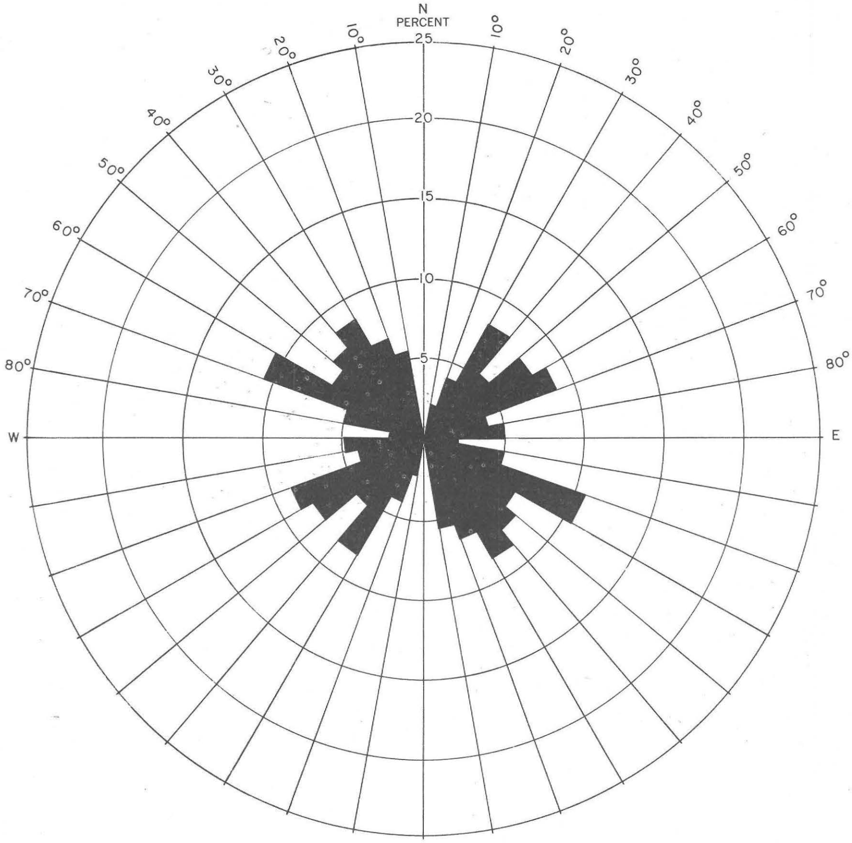

FIGURE 9.—Diagram showing the strikes of 106 steep andesite and dacite dikes from the northwestern part of the area.

PETROLOGY AND PETROGRAPHY

The complexities of the dike assemblages are difficult to unravel because of alteration, which hampers field identifications, the paucity of exposures that show crosscutting relations and textural variations within some contemporaneous dikes.

Most of the dikes are strongly altered and dark greenish gray or greenish brown by their principal alteration products, chlorite, epidote, and limonite(?). Except for the phaneritic diabase and the coarser parts of some porphyritic dikes, the dikes are mostly aphanitic. Many of the dikes are porphyritic and contain plagioclase and or hornblende phenocrysts in an aphanitic groundmass. Pyrite is dissemianted in minor amounts in many of the dikes and also occurs in veinlets that cut the dikes.

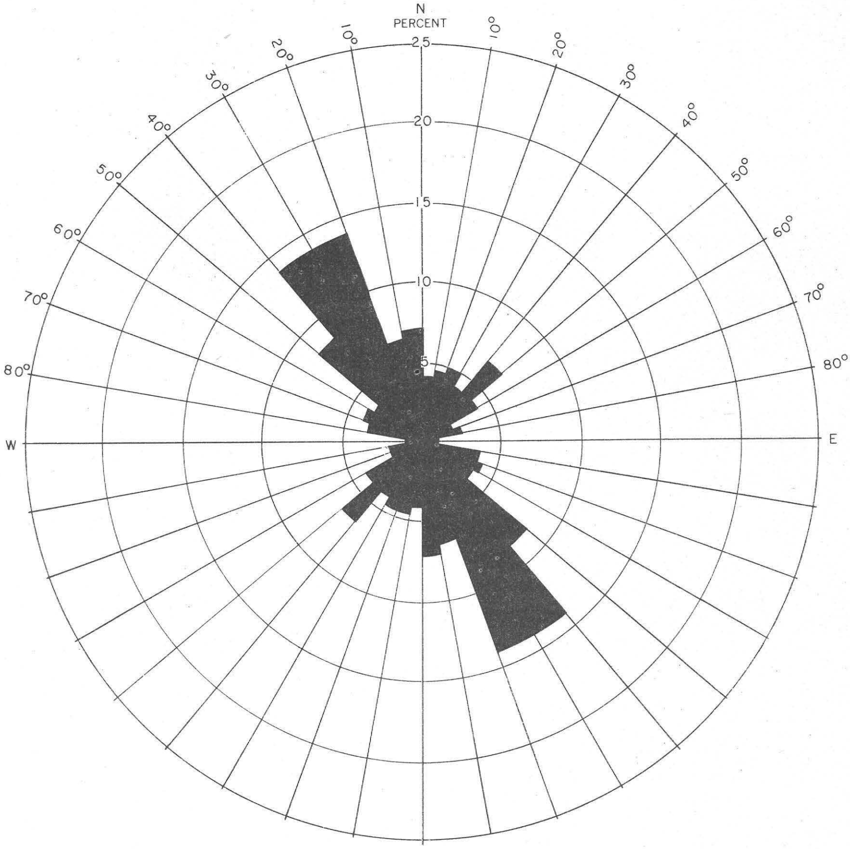

FIGURE 10.—Diagram showing strikes of 322 steep fine-grained mafic dikes from the southeastern part of the area.

Many of the dikes have exceptionally fine-grained chilled borders adjacent to their host rock. Vesicles, which in places are partly filled with calcite or quartz, are well developed in central parts of some of the dikes. Both these features as well as primary longitudinal and cross joints, which are typical of many of the dikes, are shown in figure 11.

A few of the dikes are locally platy or semischistose. The andesite and dacite dikes where exposed to salt water are generally more susceptible to erosion than their host rock or similar dikes located elsewhere. This is well shown by many of the large dikes on the shoreline of Clarence Strait between Kendrick Bay and McLean Arm. The traces of these dikes are marked by crevicelike indentations as much as 150 feet long that penetrate the land along the planes of the dikes. These features probably resulted from both

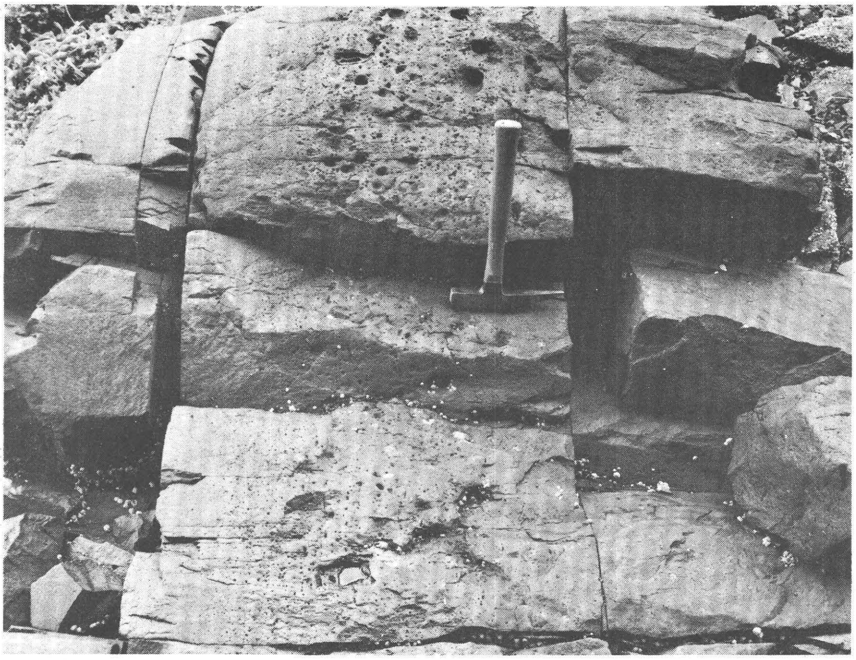

FIGURE 11.—Andesite dike showing primary longitudinal and cross joints and vesicles. The dike strikes N. 30° W. and is vertical. Photograph is of exposure 2,200 feet northeast of the mouth of Perkins Creek.

chemical and mechanical weathering. The chemical weathering was effected by the continued presence of salt water, and the mechanical weathering by strong waves generated by frequent storms and by fractures in the dikes. An illustration of the effectiveness of chemical weathering is furnished by the hornblende phenocrysts in some of the dikes. Where exposed to salt water the hornblende has been dissolved and removed, and the sites of its former crystals are voids, but in other environments hornblende generally resists weathering as well as most of the other minerals of the dikes. Inland from shorelines the dikes commonly are fairly resistant, and many of them protrude from their host rocks (fig. 11).

The andesite and dacite dikes and the minor amounts of associated lamprophyre commonly consist of subhedral or euhedral medium-grained plagioclase or hornblende phenocrysts in a very fine grained groundmass. Most of the phenocrysts are plagioclase, but in many of the dikes they are both plagioclase and hornblende. The few lamprophyres, which are the only dikes that contain hornblende as the sole phenocryst mineral, are probably minor variants of the typical andesite and dacite dikes. The nonporphyritic andesite and dacite dikes and the groundmasses of the porphyritic dikes are commonly very fine grained and felty textured. They consist chiefly of plagioclase and hornblende, but in many thin sections their primary mineralogic details are obscured by abundant secondary minerals such as epidote, clinozoisite, chlorite, and calcite.

Within a roughly concentric aureole approximately 1½ miles wide surrounding the peralkaline granite boss, the plagioclase of most andesite and dacite dikes has been converted to albite; an alteration that probably was concomitant with the formation of epidote, clinozoisite, chlorite, and some calcite. Elsewhere the plagioclase in the dikes is either andesine or oligoclase.

The mineralogy of the andesite and dacite dikes based on the examination of 16 thin sections is summarized in table 6.

TABLE 6.—*Mineralogy of the andesite and dacite dikes*

[Based on examining 16 thin sections. A, mineral occurs in 75–100 percent of thin sections; B, 50–75 percent; C, 25–50 percent; D, <25 percent]

Mineral	Distribution	Remarks
Plagioclase	A	Commonly the dominant mineral of the dikes; in very fine grained crystals and in euhedral and subhedral phenocrysts as much as 4 mm long. Prevailingly albite from dikes in northwestern part of the area, andesine or oligoclase elsewhere.
Quartz	A	Forms from less than 1 to about 25 percent of some of the dikes. Chiefly in very fine grained anhedral crystals; also in veinlets; uncommonly in medium-grained subhedral and anhedral phenocrysts.
K-feldspar	D	Forms less than 5 percent of the only dike in which it was found; in subhedral crystals about 0.5 mm long.
Hornblende	B	In euhedral phenocrysts as much as 4 mm long, but more commonly as medium- and fine-grained subhedral crystals; forms as much as 50 percent of some of the dikes; pleochroism X, pale brown or pale yellow brown; Y, yellow brown or yellow green; Z, commonly green, less commonly brown.
Biotite	C	Forms as much as 20 percent of the thin sections in which it occurs; in fine-grained subhedral crystals; pleochroism, X, colorless(?); Y, tan; Z, greenish brown or brown.
Zircon	D	In a few very fine grained euhedral crystals in one thin section.
Sphene	C	In minor amounts in fine-grained euhedral crystals; most abundant in the radioactive dikes from the Carol Ann prospects.

TABLE 6.—*Mineralogy of the andesite and dacite dikes*—Continued

[Based on examining 16 thin sections. A, mineral occurs in 75–100 percent of thin sections; B, 50–75 percent; C, 25–50 percent; D, <25 percent]

Mineral	Distribution	Remarks
Pyrite	B	Fairly abundant in fine and very fine grained crystals, chiefly euhedral, also in veinlets.
Opaque minerals (except pyrite).	B	Chiefly magnetite in fine-grained euhedral crystals; subordinate hematite and ilmenite(?); moderately abundant limonite(?).
Pyroxene (diopside?)	D	Fairly abundant in two thin sections from dikes at the Carol Ann prospects; in fine-grained subhedral crystals, 90° prismatic cleavage, (+) 2V about 45°.
Allanite	D	Moderately abundant in one thin section from a dike at the Carol Ann No. 1 prospect; in fine-grained frayed crystals; $\alpha=1.777$, $\beta=1.782$, $\gamma=1.789$, pleochroic yellow brown to dark red brown.
Apatite	C	In fine-grained euhedral crystals in minor amounts.
Fluorite	D	Purple fluorite in minor amounts in veinlets in one thin section from the Carol Ann No. 1 prospect.
Chlorite	A	Moderately abundant alteration product after mafic minerals in most thin sections.
Epidote	B	Moderately abundant alteration product of mafic minerals.
Calcite	C	As an alteration product and in veinlets.
Clay minerals	A	Alteration product of plagioclase.
Clinozoisite	C	Alteration product of mafic minerals and plagioclase.
Sericite	C	Minor alteration product of feldspars.

Several of the dikes, notably the dacite dikes at the Carol Ann prospects (pl. 1 and fig. 23), the dacite(?) dikes at the Atom Marietta prospect (pl. 1 and fig. 21), and the rhyolite(?) dike at the Geiger prospect (pl. 1), are anomalously radioactive (table 8). Their radioactivity is attributed to uranium- and thorium-bearing minerals that were introduced by hydrothermal solutions.

The rhyolite and quartz latite dikes are commonly porphyritic and contain medium-grained phenocrysts of quartz and (or) plagioclase in a very fine grained altered groundmass. They contain mineral assemblages similar to those of the andesites and dacites, but differ from these rocks by carrying more quartz and K-feldspar and much smaller quantities of mafic minerals. Near the Bokan Mountain granite boss the rhyolites and quartz latites are commonly albite bearing; elsewhere their plagioclase is oligoclase.

The diabases are fine- or medium-grained rocks that are diabasic textured. Their principal minerals are plagioclase, which is commonly normally zoned through about 5 percent anorthite within the sodic labradorite or calcic andesine range, and augite. Their lesser constituents are biotite, apatite, chlorite, epidote, opaque minerals, clinozoisite, calcite, sphene, clay minerals, and quartz.

Analyses of two dacite samples are shown in table 14 (Nos. 56AMK–79, –143B).

SURFICIAL DEPOSITS

Surficial deposits were not delineated during the areal mapping, because, although they are fairly widespread, nowhere are they sufficiently extensive or thick to prevent reasonable inferences as to the nature of the bedrock. A large part of the muskeg-covered terrain is underlain by a mantle of mucky alluvium, colluvium, or soil, but this mantle is probably not in excess of a few feet in maximum thickness. Likewise, much of the forested parts of the area is underlain by surficial deposits, but these deposits were not mapped because of evidence indicating the proximity of bedrock to the surface. Scattered striated and polished pebbles, cobbles, and boulders are remnants of glacial deposits, whose extent is too small to map. Small bodies of glacial till as much as 15 feet thick are locally exposed in roadcuts along the lower part of the Ross-Adams mine road. Small amounts of colluvium occur on the gentler slopes and valleys contiguous to some of the summit areas.

Surficial deposits have been formed on some of the beaches. They are ephemeral and are modified during periods of high waves. These deposits generally consist of well-rounded boulders or cobbles, but they include a beach of fine sand on the southern shore of Stone Rock Bay that is largely composed of quartz and feldspar with local concentrations of magnetite.

STRUCTURE

The rocks of the area are typically strongly fractured and both joints and faults are well developed. Some of the intrusive rocks are noticeably foliated, but others, such as the peralkaline granite and the syenite, that postdate the main period of orogeny, are unfoliated. Several structural features, notably minor folds, flow banding, and mullion structures, occur locally in the metamorphic and volcanic rocks, but the sparsity of exposures of these rocks limits their value in unravelling the overall structure of the area. The prevailing grain of the structure probably is northwestward. Although there are many divergences to this trend, it is revealed by the dominant faults, many of the joints, the general strike of the andesite and related dikes (figs. 9 and 10), and by some of the pendants and septa of the metamorphic rocks.

FAULTS

Faults are abundant throughout the area and are best exposed along shorelines. They are difficult to trace in areas covered by vegetation, but many of them form strong lineaments, which are readily traceable on aerial photographs. The concentration of faults plotted along the shorelines is probably a good sampling for the mapped area. They are probably equally abundant in the poorer exposed parts of the area. The trends of many of the creeks are partly controlled by faults, which in places, are well exposed along them. Parts of some of the elongate embayments are also fault controlled. One of the largest faults in the area apparently partly controlled the formation of the South Arm of Kendrick Bay. This vertical fault had right-lateral movement and is traceable from the South Arm of Kendrick Bay to near the head of McLean Arm and southward beyond the limits of mapping.

The faults generally dip between 70° and vertical and strike between N. 10° W. and N. 30° W. But exceptions to this trend are numerous, and in parts of the area northeastward-striking faults are common. A few of the faults can be traced for as much as 3½ miles, and some of these probably extend much farther.

The widths of the faults and fault zones range from a few inches to as much as 100 feet—the greatest observed width is exposed in a cut on the upper part of the Ross-Adams mine road. Some of the faults are along discrete, sharp fractures, others consist of gouge as much as 6 inches thick, and a few of breccia zones. Commonly the larger faults show all three of these features, and some of the individual breccia zones attain widths of as much as 30 feet.

The displacement on most of the faults could not be determined. Where it could, its major component was strike slip, generally between 1 and 30 feet in magnitude but some faults have much larger displacements. The largest observable movement on any one fault, about 300 feet in a left-lateral sense, is indicated by contacts offset by the fault that strikes N. 20° W. near the head of the South Arm of Moira Sound and by right-lateral movement of similar magnitude on the fault that controls the South Arm of Kendrick Bay. A few faults have had dip-slip movement. A good example of these is the steep fault north of Hill 2302 that forms part of the contact between slate and peralkaline granite. A dip-slip component of at least 100 feet is indicated for this fault; its southwest side, which is chiefly bounded by slate, was downthrown.

Some of the faults, particularly those in and near the peralkaline granite boss and also the one at the Veta prospect near Mallard Bay, have mineral deposits along them. Many of the dikes in and near the peralkaline granite boss are cut by faults that more or less parallel their trends, and many of these faults are mineralized.

JOINTS

Joints are abundant and well developed in most of the rocks. They are divisible into two main groups: primary joints attendant to the contraction accompanying the solidification of a magma and secondary joints that result from adjustments to external forces acting upon the already solidified rock. Secondary joints are much more numerous in the Bokan Mountain area.

The joints are depicted graphically on figures 12 and 13, which are contour diagrams of their poles as projected to the equatorial plane on an equal-area net. Figure 12 is based on measurements of 500 joints in the northwest part of the area, that part west of 132°05′. Figure 13 represents 375 joints from the southeastern part of the area, east of 132°05′. The prevalence of steep joints is indicated by the concentrations of the joint poles near the perimeters of the circles on both figures. Figure 12 shows that the three favored trends of the steep joints in the northwest part of the area have approximate strikes between N. 45°–60° E., N. 70°–85° W., and N. 15°–25° W. Figure 13 shows that the joints' dominant strikes in the southeastern part of the area are N. 60°–75° W., and that they dip steeply southwestward. A less conspicuous preferred orientation of the steep joints in this part of the areas is N. 20°–35° W.

Figures 12 and 13 could be more refined and made more meaningful if the joints were linked to the separate rock types, and if the primary and secondary joints were differentiated; in their present form, however, the figures at least have qualitative value.

Horizontal or near-horizontal joints are locally well developed, notably in some of the summit areas. This type of jointing can be attributed to the release of stresses accompanying denudation.

Primary joints occur in many of the rocks, but they are generally subordinate to the secondary joints in abundance and development. They localize many of the pegmatite dikes in the peralkaline granite and they are also inferred from their relations to foliation and lineation in some of the other rocks. They are especially well developed in many of the andesites and similar dikes (fig. 11), where they are indicative of contraction accompanying rapid cooling.

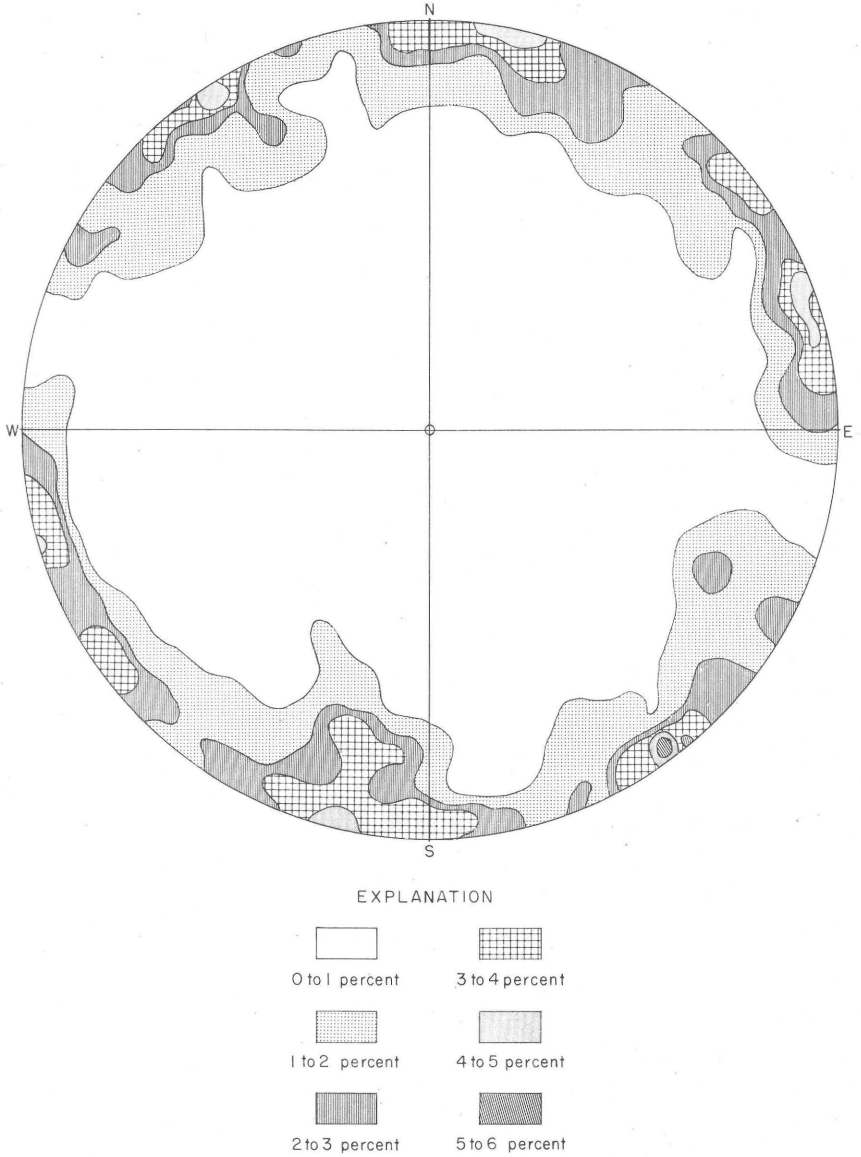

FIGURE 12.—Contour diagram of 500 joints from the part of the area west of 132°05′.

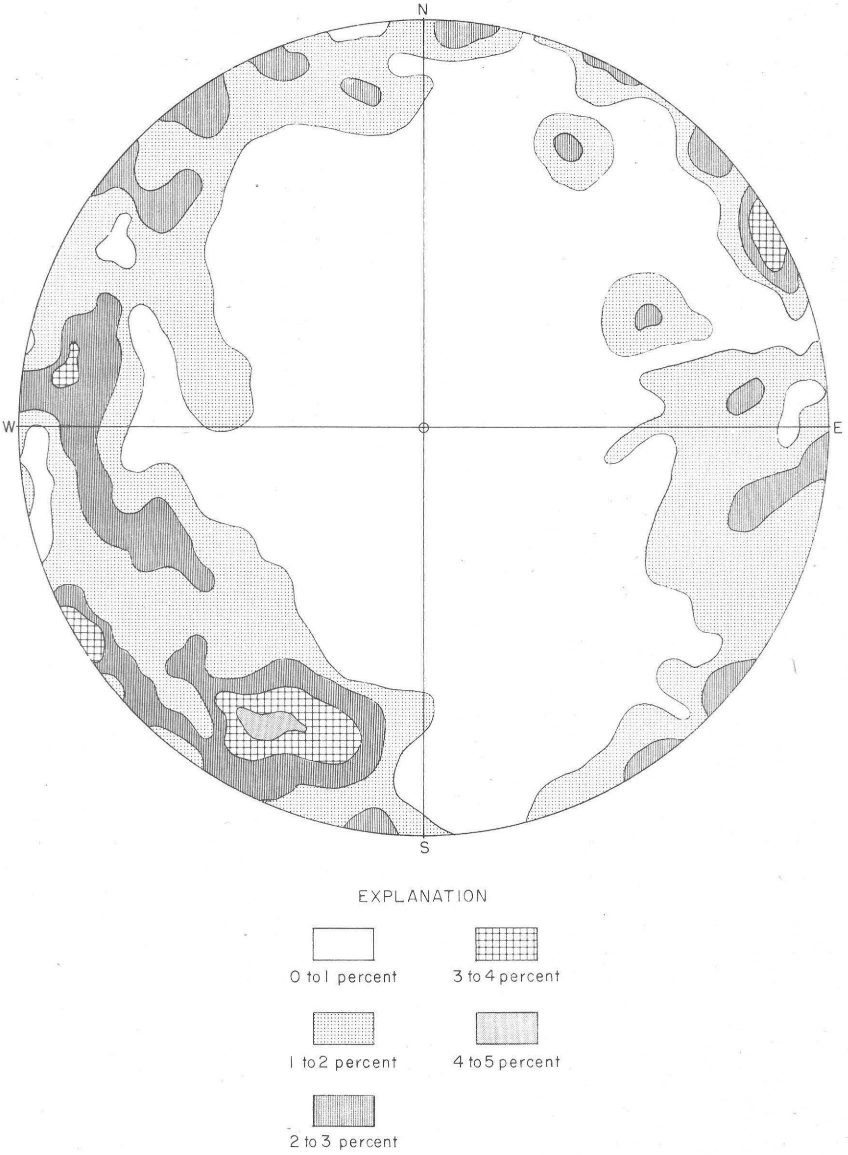

FIGURE 13.—Contour diagram of 375 joints from the part of the area east of 132°05′.

PLANAR AND LINEAR STRUCTURES IN THE PLUTONIC ROCKS

Planar structures are common in many of the plutonic rocks, most notably in the quartz diorite-diorite, granodiorite-quartz monzonite, and gneissic quartz monzonite. They are uncommon and poorly developed in the albitized intrusive rocks near the peralkaline granite boss, and in the pyroxenite, peralkaline granite, and the syenite. The planar structures are mainly the result of mafic inclusions which are commonly from 6 to 18 inches long and have parallel orientations. These inclusions range from ellipsoidal to pancakelike forms in which the lengths and widths greatly exceed the thicknesses. Other planar structures are elongate schlierenlike masses as much as 15 feet long and foliation developed by the parallel alinement of minerals, chiefly biotite, but less extensively, hornblende.

Typically, the planar structures are most abundant and best developed near the margins of the intrusive masses, particularly adjacent to metamorphic rocks. The planar elements tend to parallel the contacts between the plutonic masses, or between the plutonic and metamorphic rocks. In the latter instance they are also parallel to similar features in the metamorphic rocks. Most of the planar features dip steeply. Their strikes are diverse. Between Stone Rock Bay and McLean Arm, their prevailing trend is northeastward. Near the east and west ends of McLean Arm, this trend becomes northwestward, and to the north the trends of the planar structures largely encircle the plutonic mass occupying the summit regions between the South Arm of Kendrick Bay and Gardner Bay. Further evidence of this encirclement is the dominant northeastward trend of foliation near the South Arm of Kendrick Bay that gradually merges into the dominant northwestward-trending foliation south of the entrance to Kendrick Bay. The alinements of the amphibolite and schist bodies also conform to this general trend. Elsewhere in the area the foliation has a gross northerly trend with local divergences probably caused by the invasion of plutons.

Linear structural elements are less well developed and were not studied in detail. They occur chiefly in the quartz diorite-diorite and granodiorite-quartz monzonite, where they are marked by alined hornblende crystals that plunge steeply.

STRUCTURES IN THE METAMORPHIC ROCKS

The structures in the metamorphic rocks include folds, schistosity, gneissic banding, slaty cleavage, bedding, flow banding, and mullion structures. The folds are best developed in the slate, where they consist of minor, generally northwestward-plunging open structures that are probably superimposed on larger flexures. Minor folds occur in the schist also and are generally tight and plunge northwestward. The mullion structures are believed to be crenulations produced by the intersections of minute folds and rock cleavage.

Foliation consists of schistosity and gneissic textures, both of which are reflected by the parallel orientation of minerals, principally biotite. Commonly the foliation dips steeply. Bedding is most conspicuous in the schists, and it chiefly strikes northwestward and dips steeply southwestward. It is locally apparent in the slate, where it has diverse strikes and commonly gentle dips. Steep slaty cleavage is conspicuous in the slate, and similar cleavage occurs to a lesser extent in the schists and other metamorphic rocks. Steep flow banding has been found in layers between 1 and 20 feet thick that occur in some metavolcanic rocks near the South Arm of Moira Sound.

GEOLOGIC AND PETROLOGIC HISTORY

The geologic history of this area is largely the history of its plutonic rocks. The remnants of the Devonian(?) metamorphic rocks yield scant information, although they may be relict eugeosynclinal deposits. The postulated evolution of the intrusive rocks is as follows. The earliest stage of plutonic activity was the formation of the pyroxenite, presumably intrusive into Paleozoic sedimentary and volcanic rocks that subsequently were mostly removed by erosion. Most of the intrusive rocks apparently resulted from differentiation, largely by fractional crystallization, of a large magma body. The solidification and differentiation of this mass occurred throughout a vast time span that included both syntectonic and posttectonic periods. The transformation of preexisting rocks and their incorporation by assimilation were probably of local importance during the evolution of the magma.

The gabbro and diorite-quartz diorite probably formed from the primordial magma at an early stage, largely by fractionization, but aided by limited assimilation and transformation. Subsequently the quartz monzonite-granodiorite solidified. With decreasing temperature and pressure, the leucocratic phases of granodiorite-quartz monzonite and the gneissic quartz monzonite formed. Elsewhere magma in local small chambers diverged from the normal course of crystallization and became enriched in potassium and deficient in silica, possibly from reacting with the country rock, and solidified as syenite and monzonite. Small local end-stage crystallization produced the pegmatites and aplites that are associated with the quartz monzonite-granodiorite. The Bokan Mountain granite formed from the residuum of protracted crystallization of the dioritic rocks and quartz monzonite-granodiorite. Its parent magma was rich in sodium and many minor elements, including fluorine, and was able to persist at fairly low temperatures and pressures. The late stages of the crystallization of this peralkaline granite magma are represented by pegmatite and aplite dikes and, finally, by hydrothermal deposits.

The emplacement of the andesite and other dikes spanned a long time interval, but most of them were probably formed before the peralkaline granite and were derived from deep-seated sources.

The albitization that affected many of the rocks near the peralkaline granite boss is probably closely related temporally and spatially to the hydrothermal activity. It is conceivable, however, that some or all of this alteration resulted from earlier emanations from the peralkaline granite magma. The belief that the albitization is related to the peralkaline granite, regardless of the processes involved, is substantiated by the crudely symmetrical distribution of the albitized aureole about the peralkaline granite boss and by the general decrease in albite content in plagioclase outward from the boss. Some of the sodium may have been derived by the peralkaline granite from the assimilation of parts of the Devonian(?) metavolcanic rocks, which are mainly quartz keratophyres and consequently sodium rich. Most of the sodium in the peralkaline granite, however, probably resulted from its relative enrichment during the normal course of magmatic crystallization.

Probably the major orogeny in the area was accomplished by the end of the Cretaceous or in early Tertiary time. The Tertiary and post-Tertiary geologic history was dominated by erosion and glaciation, for which little lithologic evidence remains. The glaciers probably encroached on rugged topography and modified it by deepening and widening the valleys, in places forming cirques and sharp, steep ridges. Postglacial rises in sea level inundated many of the valleys and produced the fiordlike embayments. Glacial striae are abundant on many of the rocky summit areas, and their distribution and trends indicate that the latest glacier movements were from the northwest.

ECONOMIC GEOLOGY

Uranium ore mined from the Ross-Adams deposit during 1957 was the only uranium production recorded from Alaska as of March 1959. Besides uranium, other commodities that have intermittently interested prospectors and mining companies in the area are thorium, copper, gold, and iron. The earliest known mining activity in the area during the early 1900's resulted in the location and development of most of the copper-gold prospects. The Nelson and Tift gold mine near the mouth of McLean Arm was located in 1935.

The discovery of the Ross-Adams deposit in May 1955 inaugurated a period of fairly intensive uranium prospecting, which continued through 1956 and resulted in the location of many mining claims. Several claims for iron were staked in the pyroxenite near Mallard Bay during the summer of 1958, and a magnetic anomaly between McLean Arm and Gardner Bay has also been investigated by mining company geologists.

Other commodities of potential economic importance are rare earths, which are generally concentrated with the uranium-thorium deposits in pegmatites and in hydrothermally altered dikes and deposits of zircon and niobates in some of the pegmatites. One claim is in part for fluorite.

URANIUM-THORIUM DEPOSITS

All the known uranium-thorium deposits except a few near Gardner Bay and one on the headland between Stone Rock Bay and Mallard Bay are in or near the peralkaline granite boss. Most of these deposits are believed to have been formed chiefly by hydrothermal solutions and are probably early Tertiary in age. Several of the deposits are in the albitized aureole that surrounds the peralkaline granite boss, and the albitization and the ore deposition are probably related. Whittle (1959, p. 66) notes that many of the Australian davidite deposits are in albitized rocks. A few uranium-thorium prospects near Gardner Bay are in pegmatite dikes that are associated with quartz monzonite-granodiorite, and the one near Stone Rock Bay is in a fractured andesite(?) dike. Many anomalies of radioactivity, besides those at the prospects, were detected during the field investigations. Most of these are caused by uranium-thorium minerals in pegmatites or in mineralized fractured in or near the peralkaline granite. The intensities of the radioactive emanations commonly are low, and the radioactive minerals are generally erratically and sparsely distributed within the dikes and fractures.

The uranium-thorium deposits are divisible into four types and are considered to be mainly of hydrothermal origin. Among them are the Ross-Adams deposit, a somewhat unique deposit that originated in part from a primary segregation of uranium-thorium minerals in a late stage of the peralkaline granite magma, but to a greater extent from subsequent hydrothermal deposition; syngenetic deposits in pegmatite and aplite dikes; epigenetic hydrothermal deposits, chiefly open-space filling but including some replacement; and a deposit that occupies the interstices of clastic sedimentary rocks at the Cheri No. 1 prospect. Favored sites for the hydrothermal deposits are fractures in dikes, mainly pegmatites and aplites, in and near the peralkaline granite. These deposits are also common in faults or shear zones within or near the peralkaline granite boss.

The uranium-thorium-bearing minerals, which are predominantly primary, consist chiefly of uranothorite, uranoan thorianite, and uraninite, but they include subordinate amounts of phosphates, niobates, and complex silicates. Small amounts of secondary uranium minerals are found in some of the deposits, principally the Ross-Adams, but these minerals occur in insignificant quantities. The chief minerals associated with most of the uranium-thorium deposits are hematite calcite, fluorite, and quartz.

Most of the deposits are apparently too low grade or too small to permit mining under current (1958–59) economic conditions. Only a few of them, however, have been thoroughly explored, and the extent and overall grade of many of them are not known. Some of the deposits could probably be mined under optimum economic conditions, particularly if such byproducts as thorium, rare earths, and niobium could be marketed.

ROSS-ADAMS MINE

The Ross-Adams deposit is an uncommon type of uranium-thorium deposit in mode of occurrence, apparent genetic association with peralkaline granite, and to a lesser extent in mineralogy. The deposit has been described by MacKevett (1958, 1959a), and these descriptions will be elaborated herein.

LOCATION AND ACCESSIBILITY

The Ross-Adams mine is on the southeast flank of Bokan Mountain at an altitude of about 950 feet. Figure 14 shows the mine area as it appeared during the summer of 1956, prior to mining. Access is by the only road in the area, which is steep and unpaved and about 1¾ miles long. It was constructed during the summer of 1957 to link the mine and the dock on the West Arm of Kendrick Bay. Ill-defined trails provide shorter but more difficult routes between the mine and the West Arm of Kendrick Bay.

HISTORY AND PRODUCTION

The Ross-Adams deposit was discovered by Mr. and Mrs. Don Ross, while prospecting with an airborne Geiger counter on May 18, 1955; the discovery was confirmed by ground investigations within a few hours. During the summer of 1955, the Climax Molybdenum Co. acquired controlling interest in the property and commenced exploratory diamond drilling, which, following curtailment during the winter, was resumed on a larger scale during the summer and fall of 1956.

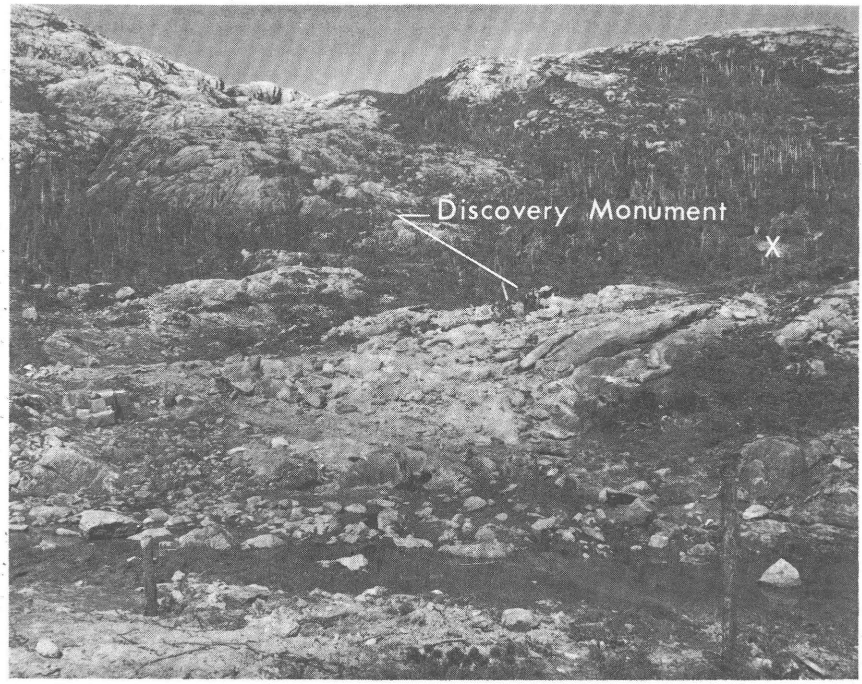

FIGURE 14.—Photograph of the Ross-Adams mine area prior to mining. Camera facing N. 20° W. The × designates a reference point in common with figure 15.

Mining took place between early July and late October 1957 and resulted in the production of approximately 15,000 tons of uranium ore that contained more than 0.80 percent U_3O_8.[1] The ore was shipped to the mill of the Dawn Mining Co. at Ford (near Spokane), Wash. The ore had a high thorium content, but costly extractive processes precluded its profitable recovery, and only uranium was recovered.

Early in the summer of 1958, the Climax Molybdenum Co. relinquished their interest in the mine, and its ownership reverted to a group of Ketchikan residents.

The mine workings consist of a northward-trending open pit about 370 feet long, between 25 and 75 feet wide, and about 30 feet in maximum depth (pl. 3 and fig. 15).

GEOLOGY

The Ross-Adams mine is within the peralkaline granite boss about a thousand feet from the southeast margin of the boss. It formed a crudely fusiform ore body that trended north and was exposed over a length of about 180 feet and averaged about 40 feet in width, and

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[1] Permission to publish production data granted by the mine owner.

its maximum vertical dimension was about 50 feet. Figure 16 is a geologic map of the mine area as it appeared prior to mining. The illustration shows the extent of the ore body's outcrop and also of its concealed parts as projected to a horizontal plane. The boundaries of the concealed ore were determined from diamond-drill-hole data and subsequent exposures in mining excavations. The few pegmatites in the mine area form quartz-rich dikes as much as 1 foot thick that contain subordinate amounts of K-feldspar and albite.

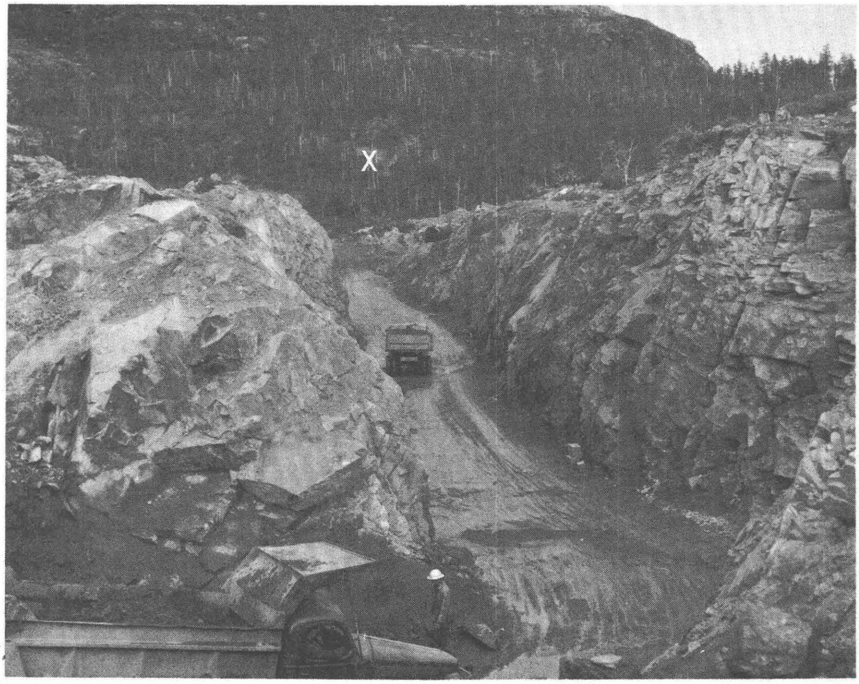
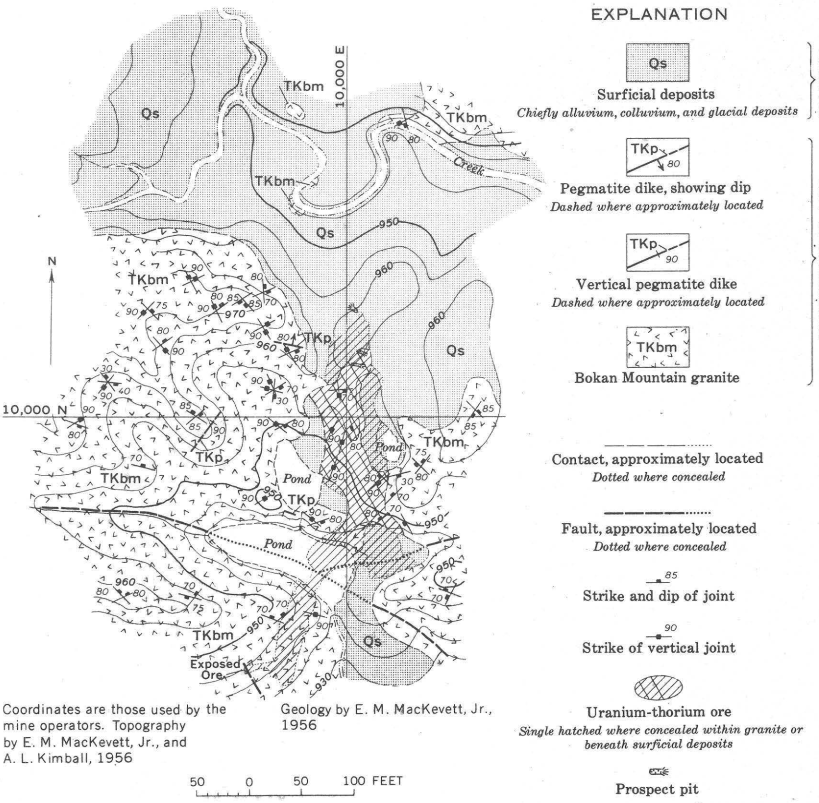


FIGURE 15.—View of the Ross-Adams open pit. Camera facing N. 10° E. The × designates a reference point common to figures 14 and 15.

Plate 3 shows the open pit as it appeared in September 1957. Scabs of ore left from the mining operations are locally exposed on the walls of the pit. The main part of the remaining ore is in the southern part of the pit where it is cut by faults. Minor amounts of ore also underlie some of the rubble on the floor of the pit. Two small slivers of andesite(?) are exposed in a fault zone in the southern part of the open pit, and andesite(?) is reported to cut peralkaline granite in some of the diamond-drill cores (H. T. Schassberger, oral communication, 1960). The andesite(?) is fragmented and commonly stained with hydrous iron oxides.



Coordinates are those used by the mine operators. Topography by E. M. MacKevett, Jr., and A. L. Kimball, 1956

Geology by E. M. MacKevett, Jr., 1956

FIGURE 16.—Geologic map of the Ross-Adams mine area, southeastern Alaska.

A better idea of the size and shape of the ore body can be obtained from figure 17, which is a generalized isometric block diagram of the deposit. This diagram is based on surface exposures, diamond-drill-hole data, and on exposures in mine excavations.

A steep fault that strikes N. 70° W. cuts another steep fault that strikes N. 80° E. where the faults are exposed in the southern part of the pit. These faults are more accurately represented by the multiple fractures shown on plate 3 than by the discrete faults that are shown in the generalized block diagram (fig. 17). Both faults cut the ore body and cause its southern part to be downthrown, but the amounts of displacement could not be accurately determined. South of the faults the ore body has only one small outcrop. This part of the lode is unmined and has not been thoroughly delineated by diamond drilling.

Many other faults are exposed in the open pit (pl. 3). Most of these are steep dipping and show little displacement, but a few of

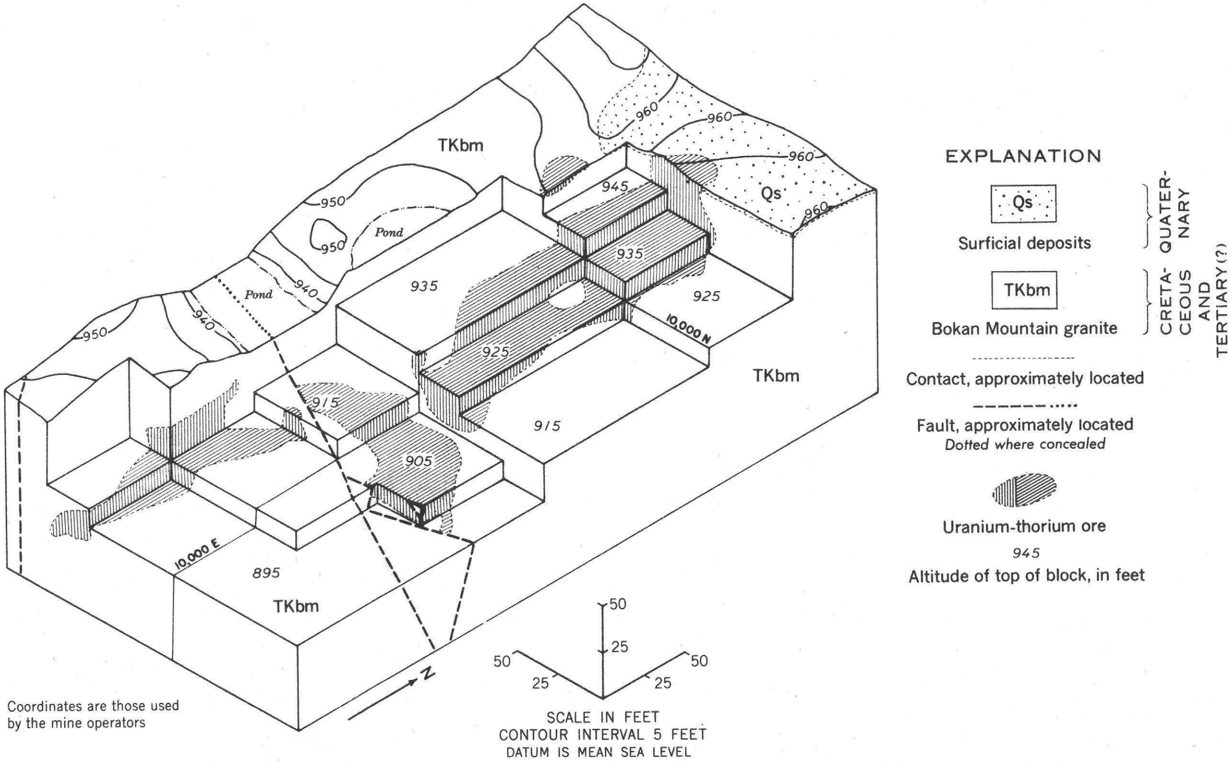


FIGURE 17.—Isometric block diagram of the Ross-Adams deposit, southeastern Alaska.

them appear to have offset the ore body. Their dominant strikes are about N. 50° W. and N. 10° E. Most of the faults are characterized by iron-stained gouge zones a few inches thick. Less commonly they contain breccia or have developed slickensides, and some of them consist of narrow iron-stained fractures that are difficult to differentiate from joints.

Joints are well developed in and near the Ross-Adams deposit (pl. 3 and fig. 16). They mainly dip steeply, but a few are nearly horizontal. Most of them are spaced at intervals 2 or 3 feet apart, but locally they are more closely spaced.

Most of the ore body has a gentle southerly plunge, which increases to about 35° near the faults exposed in the southern part of the open pit. The local steeper plunge was probably largely a drag effect of faulting.

The peralkaline granite within the mine area has several textural varieties. It ranges from fine-grained quartz-rich phases to medium-grained granites that are hypidiomorphic granular and to porphyritic varieties with coarse- or medium-grained quartz or acmite phenocrysts in a medium- or fine-grained groundmass. Acmite is the prevalent mafic mineral. The higher-grade parts of the ore body are reddish brown because of abundant hematite. They are generally bordered by a light-brown zone consisting of lower grade ore, which merges outwardly into white or buff peralkaline granite. This granite near the deposit contains more uranium-thorium minerals, fluorites, and xenotime than the average elsewhere.

MINERALOGY AND COMPOSITION OF THE ORE

In general, the Ross-Adams ore body consists of a core of high-grade ore that contains more than 0.50 percent U_3O_8 enveloped by a uraniferous zone from 2–20 feet thick that contains less than 0.50 percent U_3O_8. A large part of the high-grade ore contains about 1 percent U_3O_8, and local pods contain as much as 3 percent U_3O_8. The ore generally contains slightly more thorium than uranium, but in a few samples the thorium to uranium ratio is as much as seven to one, and the thorium content is as much as 5.66 percent (table 7). A few small irregular zones of barren rock are within the ore body. Texturally the ore resembles its peralkaline granite host rock. It consists of numerous ore-bearing veinlets between 0.1 and 0.8 mm thick and uranium-thorium minerals scattered throughout the peralkaline granite host.

Primary minerals account for almost all of the uranium and thorium values. Commonly these minerals are in the metamict state, and iron-stained fractures emanate from them, in places forming reticulating veinlets along cleavage planes in the feldspars. Figure 18 is a photomicrograph that shows scattered uranium-thorium minerals accompanied by iron-stained fractures in the peralkaline granite. The dominant ore minerals, uranothorite and uranoan thorianite, occur in crystals as much as 2 mm across that range from crudely rounded subhedral and anhedral forms to euhedral crystals (figs. 18 and 19). Both uranothorite and uranoan thorianite have been identified in several specimens by A. G. King, Jerome Stone, Daphne Riska, and Betsy Levin, all of the U.S. Geological Survey, by X-ray diffraction methods after heating the samples (written communitions, 1957). Coffinite, which occurs in minor amounts in the ore, has been identified by A. G. King (written communication, 1957) by X-ray diffraction methods.

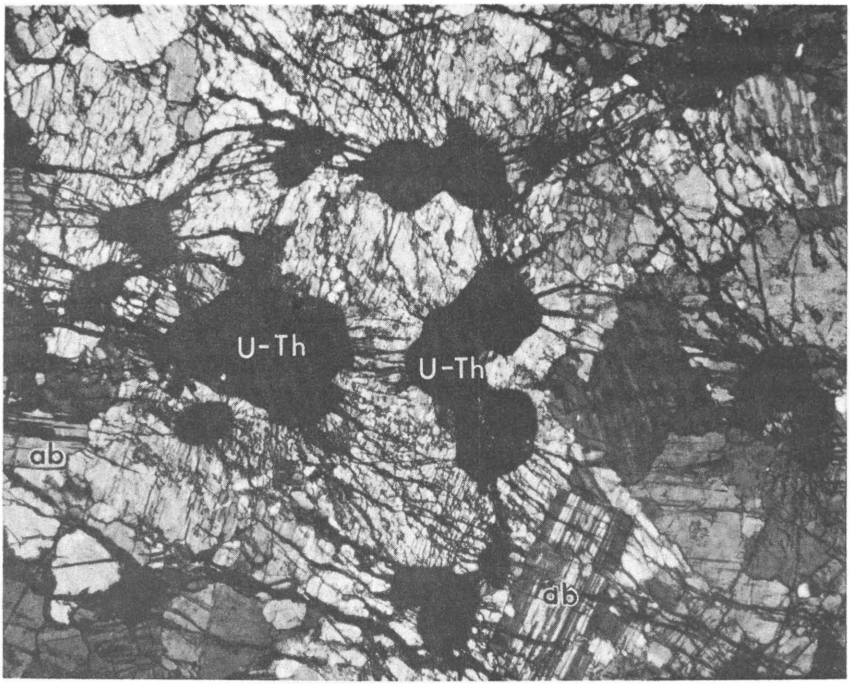


FIGURE 18.—Uranium-thorium minerals (U-Th) in peralkaline granite host. The isotropic uranium-thorium minerals are mainly uranothorite; ab is albite. The rest of the field consists mainly of quartz and sodian adularia. Crossed nicols (× 19).

Besides the uranium-thorium minerals, the veinlets contain abundant hematite and calcite, and lesser amounts of fluorite, pyrite, hydrous iron sesquioxides, galena, quartz, clay minerals, including nontronite(?), and chlorite(?). Pyrite and galena are locally abundant near the crosscutting faults at the south end of the open pit. Fluorite associated with the ore is deep purple and the quartz is gray. Photomicrographs of some of the typical vein minerals are shown in figures 19 and 20. Secondary uranium minerals occur in minor amounts in near-surface environments at the deposit. They include gummite, sklodowskite, beta-uranophane, bassetite, and novacekite, all identified by A. G. King (written communication, 1957) using X-ray diffraction methods.

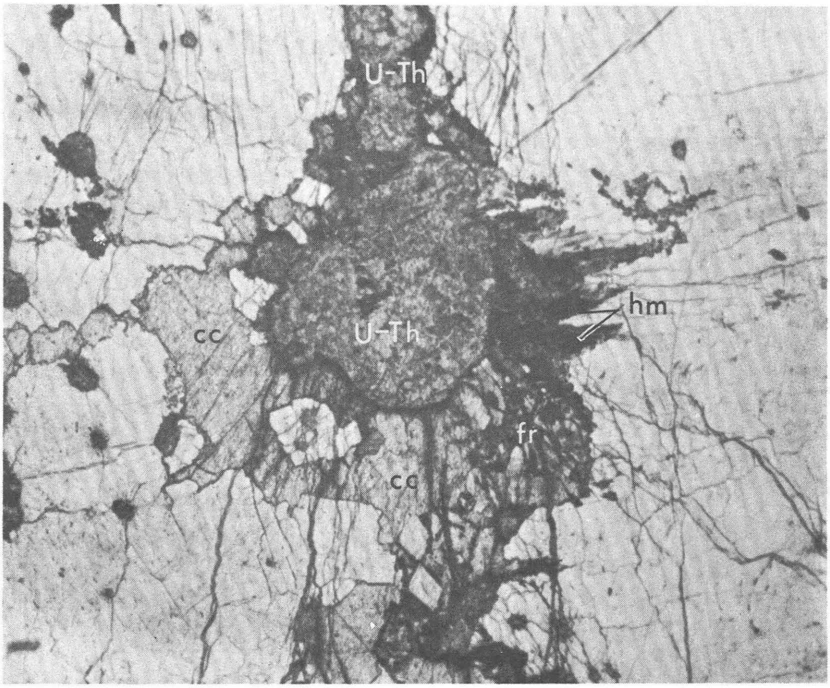


Figure 19.—A uranium-thorium-bearing veinlet showing uranoan thorianite (U-Th), calcite (cc), hematite (hm), and fluorite (fr). Iron-stained fractures emanating from the uranoan thorianite cut the other vein minerals and the peralkaline granite. Ordinary light (× 47).

The composition of the ore is indicated by table 7, which shows the results of semiquantitative spectrographic analyses for 69 elements, chemical and radiometric analyses for uranium, and chemical or X-ray fluorescence analyses for thorium. The 69 elements sought in all the semiquantitative spectrographic analyses and their standard sensitivities are shown in table 11.

Although there is a general similarity in composition between the ore and the peralkaline granite, several differences are apparent from comparing tables 7 and 13. Notable among these are the increase in uranium and thorium in the ore and its lack of potassium.

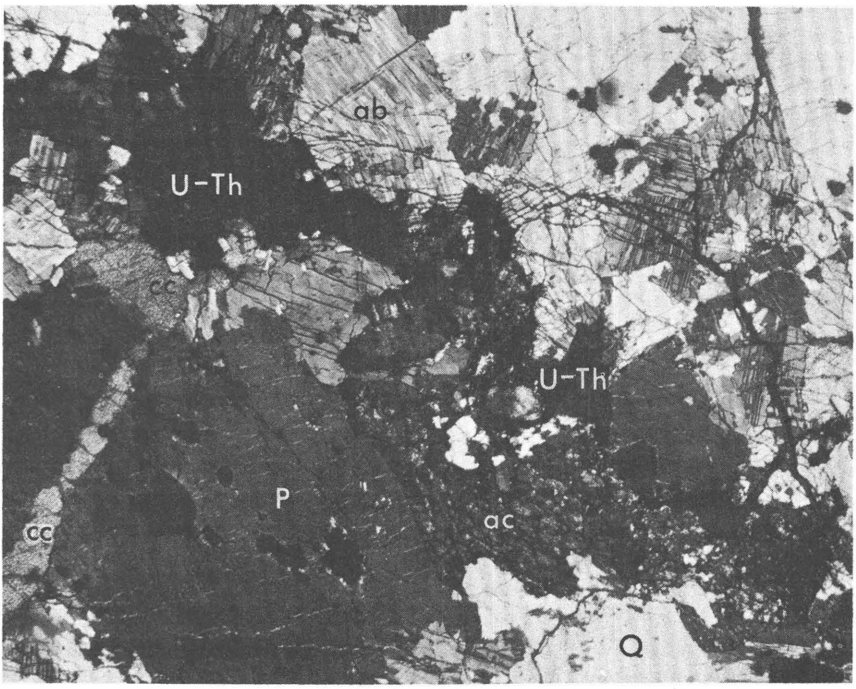


Figure 20.—Uranium-thorium minerals (U-Th) in a veinlet in peralkaline granite. Other minerals in the field are calcite (cc), microperthite (P), quartz (Q), acnite (ac), and albite (ab). Note the deformation of some of the crystals and the local fracturing. Partly crossed nicols (× 20).

The ore also differs from the peralkaline granite by generally containing more iron, lead, and aluminum, and slightly more zirconium, titanium, magnesium, calcium, manganese, and arsenic. The enrichment of iron and some of the lead and the minor enrichment of arsenic are attributed to hydrothermal activity. The Ross-Adams deposit contains notable quantities of niobium and certain rare earths. The minor elements assemblage, however, is less varied and smaller than in many of the other deposits (tables 8 and 9).

Most of the deposit is out of radioactive equilibrium in such a way that the radioactivity of the thorium combines with that of the uranium to give an effect of apparent equilibrium, and most equivalent and chemical uranium analyses of the same sample are nearly equal (table 7) despite the presence of abundant thorium. The cause of this inequilibirum is not known.

An isotopic analysis of galena from the Ross-Adams mine, made by L. R. Stieff and T. W. Stern, of the U.S. Geological Survey, showed the following atom percents of the lead isotopes: Pb^{204}, 0.857;

TABLE 7.—*Semiquantitative spectrographic analyses, equivalent and chemical uranium analyses, and six thorium analyses of ore from the Ross-Adams deposit*

[Semiquantitative spectrographic analyses by Joseph Haffty, U.S. Geol. Survey. Values for spectrographic analyses in percent to the nearest number in the series, much greater than 10, 10, 3, 1, 0.3, 0.1, 0.03, 0.01, 0.003, 0.001. Dashes indicate not detected. Standard sensitivities for the elements sought in the semiquantitative spectrographic analyses are shown in table 11]

Sample	Percent—			Ag	Al	As	Ba	Be	Ca	Ce	Co
	cU[1]	eU[2]	Th								
56AMK-36-2	0.64	0.61	[3] 0.74	<0.001	(4)	0.01	0.03	0.001	0.1	------	0.003
40-1	.38	.38	(5)	<.001	(4)	.01	.003	.001	.03	.01	.001
40-3	.56	.53	(5)	<.001	(4)	.01	.01	.001	.03	------	.001
41-1	.18	.20	(5)	<.001	(4)	.01	.01	<.001	.03	------	.001
42-2	.36	.40	(5)	<.001	(4)	.01	.01	.001	.03	------	.003
42-4	.60	.69	(5)	<.001	(4)	.01	.01	.001	.1	------	.003
43-1	1.8	1.6	[3] 2.20	<.001	(4)	.01	.03	.001	.1	------	.003
43-3	.55	.63	(5)	<.001	(4)	------	.01	.001	.03	------	.001
44	3.2	4.4	[6] 5.66	<.001	3	------	.03	<.001	.3	.1	------
45	2.8	2.3	[6] 2.32	<.001	3	------	.03	<.001	.1	------	------
46	1.3	1.6	[3] 1.62	<.001	10	.01	.1	.001	.3	------	.003
50	.60	3.1	[6] 3.34	<.001	3	------	.03	.001	.1	------	------

Sample	Cr	Cu	Dy	Er	Fe	Ga	La	Mg	Mn	Mo	Na	Nb
56AMK-36-2	0.003	0.001	0.03	0.03	(4)	0.003	0.01	0.1	0.1	------	3	0.01
40-1	.003	.001	.03	.03	(4)	.003	.03	.03	.03	------	3	.01
40-3	.003	.001	.03	.03	(4)	.003	------	.03	.03	------	3	.01
41-1	.003	.001	------	------	(4)	.003	------	.03	.03	------	3	.03
42-2	.001	.001	.03	.03	10	.003	.01	.1	.1	------	3	.01
42-4	.001	.001	------	------	10	.003	------	.1	.1	------	3	.01
43-1	.001	.01	.03	.03	10	.003	.01	.03	.03	0.003	3	------
43-3	.001	------	.01	------	10	.003	.01	.03	.03	------	3	.01
44	.001	.001	.03	.03	3	.003	.03	.03	.1	------	3	.01
45	.001	.003	.03	.03	3	.003	------	.03	.1	------	3	.01
46	.001	.001	.03	.03	10	.003	------	1	.3	.003	3	------
50	.001	.001	.03	.03	3	.003	------	.1	.1	------	3	.01

Sample	Nd	Pb	Si	Sn	Sr	Th	Ti	U	V	Y	Yb	Zr
56AMK-36-2	0.01	0.03	(4)	0.003	0.01	1	0.3	1	------	0.1	0.03	1
40-1	.03	.01	(4)	.003	.001	1	.3	.3	------	.1	.03	1
40-3	------	.03	(4)	.003	.001	1	.3	.3	------	.1	.03	1
41-1	------	.01	(4)	.003	.001	0.3	.3	.1	------	.03	.003	.1
42-2	.01	.03	(4)	.003	.001	1	.1	.3	------	.1	------	.3
42-4	.01	.03	(4)	.003	.001	1	.1	1	------	.03	.003	.03
43-1	.03	.1	(4)	.003	.003	3	.1	3	------	.1	.03	.3
43-3	.01	.03	(4)	.003	.001	1	.1	.3	------	.08	.01	.3
44	.03	.3	(4)	------	.01	3	.3	3	0.003	.1	.01	.1
45	------	.3	(4)	------	.03	3	.3	3	.001	.1	.01	.3
46	------	.1	(4)	.003	.03	3	.1	1	.001	.1	.01	.3
50	------	.3	(4)	------	.01	3	.1	1	.001	.1	.01	.3

[1] Chemical uranium analyses by Roosevelt Moore, U.S. Geol. Survey.
[2] Radiometric analyses by B. A. McCall, U.S. Geol. Survey.
[3] X-ray fluorescence analyses for thorium by Isidore Adler, U.S. Geol. Survey.
[4] Much greater than 10.
[5] Not analyzed for thorium except by semiquantitative spectrographicanalyses.
[6] Chemical analyses for thorium by Esma Campbell, U.S. Geol. Survey.

Pb^{206}, 41.301; Pb^{207}, 14.645; and Pb^{208}, 43.193. According to Stieff and Stern (written communications, 1958)

This galena is substantially enriched in radiogenic Pb^{206} and Pb^{208} relative to Pb^{204}. It is unique to our knowledge in that the Pb^{207}/Pb^{204} ratio is low, approximately 17 : 1 and does not reflect the addition of radiogenic Pb^{207} as every other enriched analysis does. If the isotopic analysis is correct, and it appears to be, then the radiogenic daughter products from the U^{235}-Pb^{207} series were separted by some geologic process from the U^{238}-Pb^{206} series daughter products. It is not surprising that some separation of isotopes, by geologic processes within the different decay series would occur. What is difficult to accept is the large radiogenic additions and the completeness of the separation between radiogenic Pb^{206} and Pb^{207}.

PROBABLE GENESIS OF THE ORE

The formation of the Ross-Adams deposit is probably attributable to two processes: first, a local concentration of small amounts of late-stage accessory uranothorite and uranoan thorianite in the peralkaline granite, and, second, the subsequent formation of numerous uranium- and thorium-bearing veinlets at the site of the lode. The second process formed most of the ore. Possibly some of the uranium and thorium minerals in the veinlets were derived from reworking the earlier accessory uranium-thorium minerals, but it is unlikely that this mechanism was very effective.

The causes of the postulated local concentration of the accessory uranium-thorium minerals are not well understood. No structures that would favor the accumulation of the accessory uranium-thorium minerals during the crystallization of the peralkaline granite were recognized at the site of the deposit.

The hydrothermal activity occurred subsequent to the crystallization of the peralkaline granite and probably was facilitated by some of the faults, particularly the strong faults exposed in the southern part of the open pit, which may have acted as channelways for the vein-forming hydrothermal solutions. It is postulated that these faults had at least two periods of activity and that they were open channels during the period of hydrothermal activity. Later movements on them offset the ore body. The ore deposit attains its widest dimension near the faults, and minor amounts of finely crushed ore and vein minerals and secondary iron minerals occur along the faults. Similar faults localize hydrothermal uranium-thorium-fluorite-hematite and rare-earth deposits elsewhere in the area.

The uncommon secondary uranium minerals resulted from the oxidation of some of the uranium of the primary radioactive minerals to the plus-six valence state and its subsequent fixation in secondary uranium minerals.

The Ross-Adams deposit appears to be somewhat unique among the uranium-thorium deposits of the world. It has some similarities with certain deposits in the Bancroft region of Ontario, Canada, particularly in mineralogy and in association with late-stage granitic rocks. Robinson and Hewitt (1958), who describe these deposits, note that uraninite and uranothorite are the principal ore minerals and that uranoan thorianite is a lesser constituent. Zircon and calcite, minerals that are fairly common in the Ross-Adams deposit, are abundant in the Bancroft deposits. These deposits, however, also contain an assortment of other minerals that have not been found in the Ross-Adams deposit. The Bancroft deposits are generally larger and lower in grade than the Ross-Adams deposit; and although there are several types of deposits in the Bancroft region, the only production there has been from pegmatitic granites.

ATOM MARIETTA PROSPECTS

INTRODUCTION

The Atom Marietta prospects are on several claims that were located by R. L. Dotson and Joseph Blazek during the summer of 1955. Most of the known deposits are on the Atom Marietta No. 4 claim, which is about 1,600 feet N. 73° E. of the Ross-Adams mine between altitudes of 800 and 920 feet. The prospects are mainly in a steep ravine, and the few natural exposures are in the bottom of the ravine or along its walls, where they are largely confined to landslide scars. Many of the highest grade samples were obtained from landslide debris. Access is by a steep trail from near the summit of the Ross-Adams mine road.

The prospects have not been extensively explored, and the only workings are small hand-dug cuts and pits. The Atom Marietta No. 4 prospects consist of minor surficial cuts at the westernmost (discovery) prospect at altitudes between 890 and 900 feet (fig. 21), and similar workings about 200 feet to the north at an altitude of 860 feet, and on a slide about 200 feet N. 70° E. at an altitude of 890 feet.

GEOLOGY

The Atom Marietta prospects are in the albitized zone peripheral to the peralkaline granite boss and are within a few hundred feet of the boss's southeastern margin. The prospects are near the intersection of a large northeastward-trending fault zone, which is well exposed on the Ross-Adams mine road, and a group of steep northwestward-striking faults that cut the fault zone. The nearby rocks are strongly fractured and altered. An aplite mass that intervenes between the peralkaline granite and the leucocratic quartz monzonite to the northeast is the commonest rock near the prospects. The aplite is cut by a strongly fractured dacite(?) dike, or dikes, of undetermined dimensions. The dacite(?) is a strongly altered very fine grained rock that is dark gray on fresh surfaces and weathers brown. It is localized largely in and near the fault zones and, besides its strong alteration, is characterized by abundant sheared and slickensided surfaces with many divergent trends.

ORE DEPOSITS

The ore deposits are confined to the altered and fractured dacite(?) within or near the shear zones, or they are distributed along the fractures of the shear zones. Figure 21 shows the geologic setting of the westernmost workings at the Atom Marietta No. 4 prospect. The distribution of the uranium-thorium minerals is indicated by the intensity of the radioactivity that is shown in the figure. At the westernmost prospect a steep shear zone that strikes N. 80° W. cuts a component of the northeastward-striking shear zone, and uranium-thorium minerals occur locally in both shear zones and in the adjacent dacite(?).

Uranium-thorium minerals occur along two parallel shear zones, each about 1½ feet thick, that strike N. 5° W. and dip 80° SW. on the north side of the creek about 200 feet north of the westernmost prospect. At this prospect the country rock is altered dacite(?) and the maximum radioactivity is 1.5 mr per hr (milliroentgens per hour) against a background of 0.02 mr per hr. South of the creek where these shear zones cut aplite, the maximum radioactivity is 0.2 mr per hr. A fault zone 2 feet thick that strikes N. 60° W. and dips 70° NE. is exposed at the head of the slide about 200 feet N. 70° E. of the westernmost workings. Slickensides on the footwall of this fault rake 17° NW. The maximum radioactivity at this site is 0.2 mr per hr. Both dacite(?) and aplite form small outcrops in the vicinity, and several high-grade ore samples have been collected from the slide rubble. Fractured and altered dacite(?) that emits anomalous radioactivity to the extent of 0.2 mr per hr is exposed in two small pits about 50 feet northeast of the slide.

The uranium-thorium minerals occur in narrow veinlets, in disseminations, and in irregular sublinear assemblages (fig. 22). They include uranothorite and uraninite, other primary radioactive minerals that were not identified, and very minor amounts of a secondary uranium mineral, probably uranophane. Uranothorite is probably the most abundant ore mineral, and it forms irregular crystals as much as 0.5 mm across. The uraninite is generally disseminated in very fine grained crystals that are less than 0.1 mm across. The unidentified primary radioactive mineral, probably brannerite or davidite, also occurs in very fine crystals. The gangue minerals at the Atom Marietta deposits are hematite, calcite, quartz, chlorite, and fluorite.

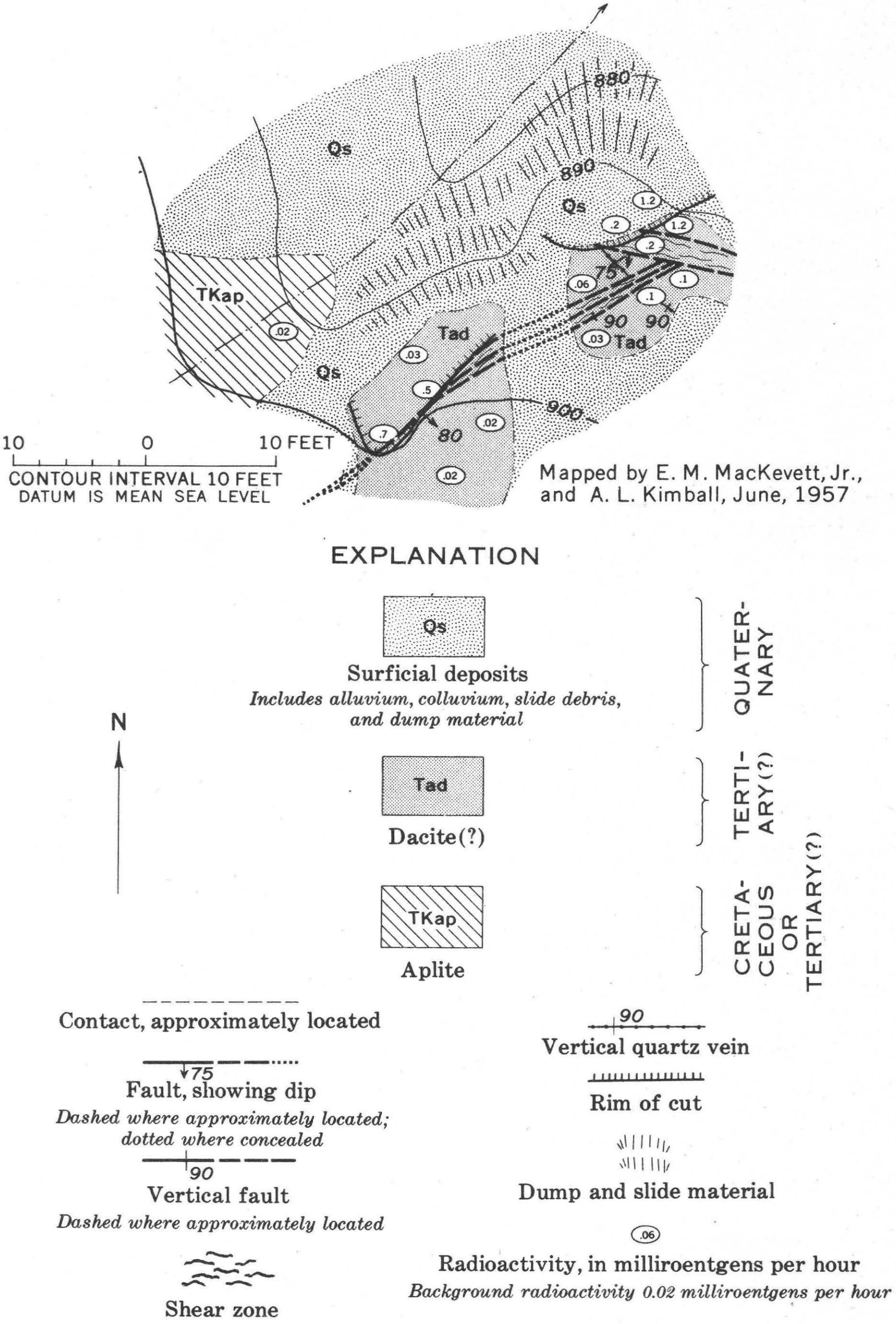


FIGURE 21.—Geologic sketch map of the westernmost workings, Atom Marietta No. 4 claim.

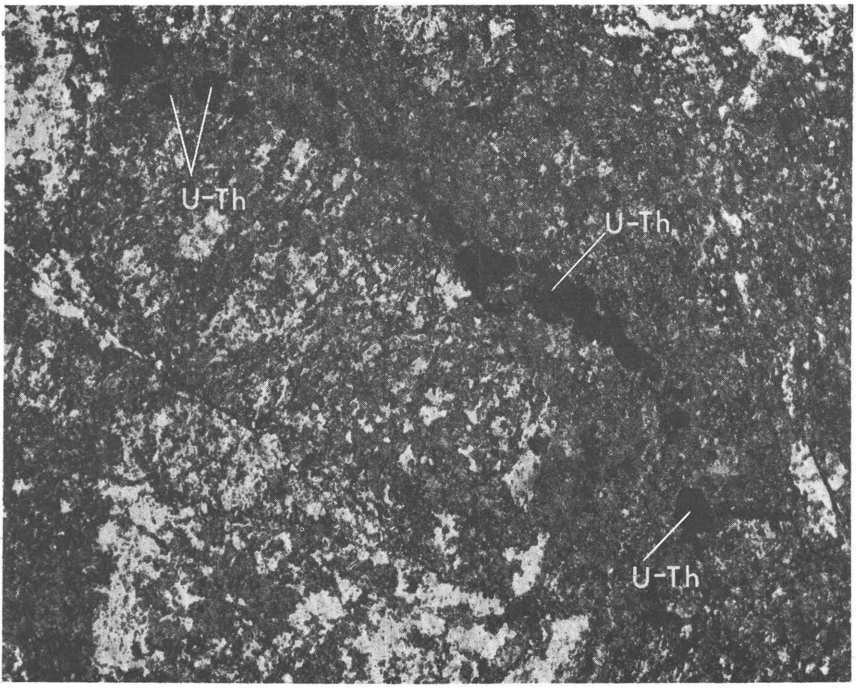


FIGURE 22.—Sublinear assemblage of opaque uranium-thorium minerals (U-TH), probably uranothorite, in altered fine-grained dacite(?). Crossed nicols (×31.5).

Analyses of three samples of the uranium-thorium-bearing dacite(?) that constitutes the ore at the Atom Marietta prospects are shown in table 8. The first two samples (Nos. 56AMK–82 and 57AMK–2) are from the westernmost prospect, and the other one (No. 57AMK–3) represents float from the slide to the northeast. Along with the influx of uranium and thorium these samples show additions of rare earths and many other minor elements when compared with samples of unaltered dacite (table 14). They are similar in many respects to samples from the Ross-Adams deposit (table 7). In contrast to the Ross-Adams ore, these samples have a fairly high uranium to thorium ratio, which is probably indicative of uranium-rich minerals, such as uraninite, being more abundant in the Atom Marietta deposits than is apparent from the microscopic studies.

A hand specimen of slide material from the westernmost workings, assayed by the Alaska State Division of Mines and Minerals, contained about 9.0 percent U_3O_8. Only a small amount of uraninite could be identified in this sample and most of the uranium values are attributed to an unidentified radioactive black mineral, probably davidite or brannerite, with a large uranium to thorium ratio.

TABLE 8.—*Semiquantitative spectrographic analyses, equivalent and chemical uranium analyses, and two thorium analyses of radioactive samples from the prospects*

[Semiquantitative spectrographic analyses by Joseph Haffty and H. W. Worthing, U.S. Geol. Survey. Standard sensitivities for the elements sought in the semiquantitative spectrographic analyses are shown in table 11. Values for spectrographic analyses in percent to the nearest number in the series, much greater than 10, 10, 3, 1, 0.3, 0.1, 0.03, 0.01, 0.003, 0.001. Dashes indicate not detected. This table excludes the I and L prospects]

Sample	Name	Location	Percent—			Ag	Al	As	B	Ba
			cU [1]	eU [2]	Th					
56AMK-82	Altered dacite(?).	Atom Marietta.	2.8	2.1	[3]0.13	<0.001	3	------	------	0.03
57AMK-2	Altered dacite(?).	do	.25	.28	(5)	<.001	10	------	0.003	.1
57AMK-3	Altered dacite(?).	do	1.3	1.3	(5)	<.001	10	------	.003	.1
56AMK-70	Altered dacite	Carol Ann No. 1.	.028	.037	(5)	<.001	3	------	------	.01
56AMK-187	Impure quartzite.	Cheri No. 1	.06	.075	(5)	.0003	3	0.01	.1	.003
57AMK-55	Pegmatite	I, L, and M No. 2.	.26	.25	(5)	<.001	3	------	------	.1
56AMK-166A	Pegmatite	Little Jim	.095	.10	(5)	.001	.3	------	------	.01
56AMK-232B	Altered peralkaline granite and veinlets.	Wennie (Lazo group).	.026	1.9	[6]7.17	------	1	------	------	.01
56AMK-229A	Altered aplite	Boots	.034	.040	(5)	<.001	10	------	------	.01
56AMK-236B	Altered rhyolite(?).	Geiger	.028	.033	(5)	<.001	3	------	------	.01

Sample	Be	Ca	Ce	Co	Cr	Cu	Dy	Er	Eu	Fe	Ga
56AMK-82	0.001	1	------	------	0.01	0.01	0.03	0.03	------	3	0.003
57AMK-2	.001	10	0.01	0.001	.03	<.001	.003	------	0.001	10	.003
57AMK-3	.003	10	.01	.001	.03	.03	.01	------	.003	10	.003
56AMK-70	.003	.3	.3	------	.003	.001	.03	.03	------	1	.003
56AMK-187	------	3	1	------	.003	.001	.3	.3	.03	10	.001
57AMK-55	.001	.1	.1	<.001	<.001	.003	.1	.03	.01	1	.003
56AMK-166A	<.001	.01	------	------	.001	.001	.03	.1	------	10	------
56AMK-232B	.01	.1	1	------	------	.003	1	1	.1	10	------
56AMK-229A	<.001	.1	------	------	.001	.003	.03	.03	------	3	.001
56AMK-236B	.001	.1	------	------	.001	.001	.01	.03	------	3	.001

Sample	Gd	Hf	Ho	K	La	Li	Lu	Mg	Mn	Mo	Na
56AMK-82	------	------	------	------	------	------	------	1	0.1	------	3
57AMK-2	------	------	------	3	------	0.03	------	3	.3	0.003	3
57AMK-3	0.03	------	------	1	0.01	------	------	3	.3	<.001	3
56AMK-70	------	------	------	------	.1	.01	------	.3	.1	------	3
56AMK-187	.1	------	0.01	------	.3	------	------	.1	.1	------	.3
57AMK-55	.1	0.03	.01	1	.1	------	0.01	.003	.03	------	.03
56AMK-166A	------	.03	.003	------	.01	------	.01	.01	.1	.03	.1
56AMK-232B	.3	------	.03	------	.1	------	.1	.01	.1	------	------
56AMK-229A	------	.03	------	.3	.01	------	.003	.1	.01	.003	3
56AMK-236B	------	.03	------	.3	.01	------	.003	.01	.03	.001	1

Sample	Nb	Nd	Ni	P	Pb	Pn	Sc	Si	Sm	Sn	Sr
56AMK-82	0.01	------	0.003	------	0.1	------	0.003	(4)	------	0.003	0.03
57AMK-2	.003	------	.01	------	.01	------	.003	(4)	------	------	.03
57AMK-3	.003	------	.01	------	.03	------	.001	(4)	------	.001	.1
56AMK-70	.1	0.1	------	------	.3	------	.003	(4)	------	.01	.01
56AMK-187	.1	.3	------	------	.03	0.1	------	(4)	0.1	.03	.03
57AMK-55	1	.1	------	------	.3	.01	.001	(4)	.01	.03	.01
56AMK-166A	.1	------	------	------	.003	------	------	(4)	------	.03	------
56AMK-232B	.1	.3	------	3	.03	.03	------	(4)	.3	------	.01
56AMK-229A	.1	.01	.01	------	.003	------	------	(4)	------	------	.003
56AMK-236B	.1	.01	------	------	.03	------	------	(4)	------	.03	.003

See footnotes at end of table.

Table 8.—*Semiquantitative spectrographic analyses, equivalent and chemical uranium analyses, and two thorium analyses of radioactive samples from the prospects*—Continued

Sample	Ta	Tb	Th	Ti	Tm	U	V	Y	Yb	Zn	Zr
56AMK-82	------	------	0.1	1	------	3	0.003	0.1	0.01	------	0.03
57AMK-2	------	------	.1	.3	0.001	.3	.01	.03	.003	0.03	.1
57AMK-3	------	------	.3	1	.003	1	.01	.1	.01	.01	.03
56AMK-70	------	------	------	.1	------	------	------	.1	.003	.03	.03
56AMK-187	------	------	.1	.1	------	------	------	1	.1	.03	1
57AMK-55	0.01	0.01	.03	.1	.01	.3	<.001	1	.1	------	3
56AMK-166A	------	------	.1	1	------	------	------	.3	.1	------	3
56AMK-232B	------	.1	3	.1	.1	.3	------	3	.3	------	.03
56AMK-229A	------	------	.1	.1	------	------	------	.1	.03	.1	1
56AMK-236B	------	------	------	.3	------	------	------	.1	.03	.01	3

[1] Chemical uranium analyses by Roosevelt Moore and Joseph Budinsky, U.S. Geol. Survey.
[2] Radiometric analyses by B. A. McCall, U.S. Geol. Survey.
[3] Chemical thorium analysis by Esma Campbell, U.S. Geol. Survey.
[4] Much greater than 10.
[5] Not analyzed for thorium except by semiquantitative spectrographic methods.
[6] X-ray fluorescence thorium analysis by Isidore Adler, U.S. Geol. Survey.

CAROL ANN PROSPECTS

INTRODUCTION

The Carol Ann prospects are on three claims that were located during the summer of 1955 by John Worthington, Kenneth McKern, and W. B. Jucius. The claims trend northwestward from tidewater on the West Arm of Kendrick Bay to an altitude of about 450 feet. Their scant workings consist of small surficial clearings and pits that expose bedrock on the No. 1 prospect (fig. 23), which lies nearest to Kendrick Bay, and on the No. 2 prospect, the most northwestward of the group, and small prospect pits on the No. 3 claim, which is between the other two claims. The No. 1 and No. 3 claims are mainly on fairly steep, densely forested hillside, but a large part of the No. 2 claim consists of a gentle-sloping muskeg-covered tract. Access is by a blazed trail from the West Arm of Kendrick Bay.

GEOLOGY

The Carol Ann prospects are on a series of steep subparallel radioactive dacite dikes that strike N. 60°–75° W. All of the prospects are within the albitized aureole that surrounds the peralkaline granite boss. The No. 1 prospect (fig. 23) is close to the contact between quartz diorite and quartz monzonite; the dominant country rock at the No. 2 prospect is quartz monzonite, and at the No. 3 prospect, quartz diorite.

Quartz-rich altered dacite dikes that are locally anomalously radioactive are exposed in several small prospect pits and opencuts at the No. 1 prospect. The most radioactive of these dikes is exposed in an opencut for a width of about 6 feet and a height of about 8 feet (fig. 23). This dacite is gray and weathers brown, but parts of it are stained black by manganese or iron minerals. It contains abundant

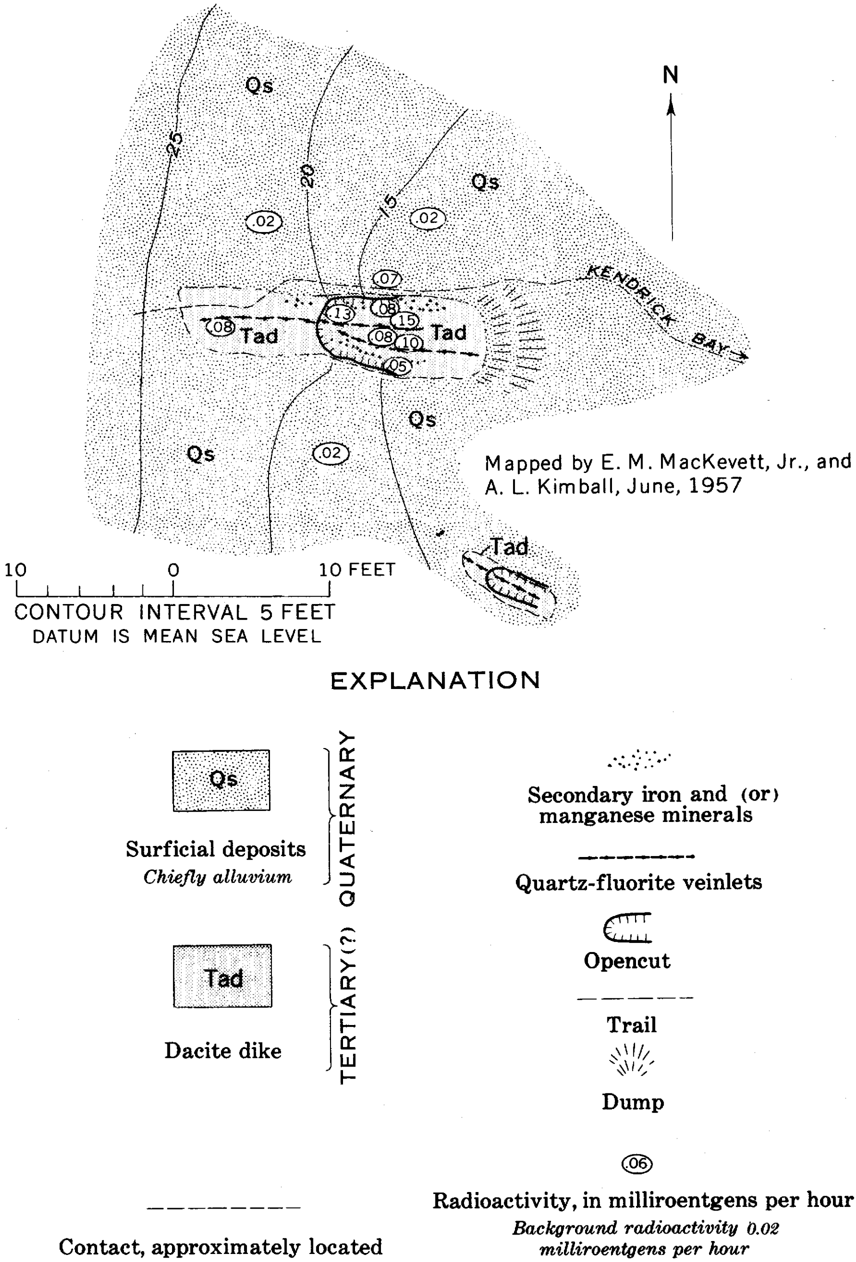


FIGURE 23.—Geologic sketch map of the Carol Ann No. 1 prospect.

quartz-rich veinlets as much as 2 cm thick, some of which have pegmatitic or aplitic facies. Besides quartz the veinlets contain purple fluorite, minor amounts of allanite, and a few small crystals of an unidentified radioactive black that is associated with the fluorite. Fluorite and allanite also occur in nearby parts of the dikes. Allanite is the chief source of the anomalous radioactivity.

Analyses of a chip sample of the radioactive dike taken across the exposure shown in figure 23 are shown in table 8 (No. 56AMK–70).

At the Carol Ann No. 2 prospect the bedrock has been scraped clear of overburden and is exposed over an area of about 150 square feet. This exposure reveals albitized light-colored quartz monzonite that is cut by a vertical dacite dike 6 feet thick that strikes N. 75° W. A diabase dike, a few inches thick, occurs along the southwest wall of the dacite dike. The anomalous radioactivity, a maximum of 0.15 mr per hr against a background of 0.02 mr per hr, is associated with quartz stringers that cut the dacite. Allanite is the dominant radioactive mineral. It occurs in the quartz veinlets and in the nearby parts of the dacite.

A similar dacite dike is exposed at the No. 3 prospect, where it attains a maximum thickness of 3 feet. This dike strikes N. 70° W. and dips vertically. It is locally radioactive and emits a maximum radioactivity of 0.60 mr per hr against a background of 0.02 mr per hr. Allanite is the host mineral for the radioactive elements. The dacite dike is banded with quartz veinlets in roughly parallel alinement. The veinlets are as much as 5 mm thick and are interspersed between the fine-grained quartz and albite of the dike. Parts of the dike are porphyritic with anhedral quartz phenocrysts as much as 3 mm across in a fine-grained groundmass. Less abundant minerals in the dikes are sphene, allanite, clinozoisite, clay minerals, sericite, magnetite, and remnants of pyroxene that has been largely replaced by allanite.

The Carol Ann deposits probably were derived from late-stage fluids that emanated from the peralkaline granite. These fluids formed veinlets in the fractures in the dikes and introduced the uranium and thorium and the other uncommon elements of the deposits. They probably were closely linked genetically and spatially to the fluids that caused the albitization.

CHERI PROSPECTS

INTRODUCTION

The Cheri prospects are on several claims that extend about 2,000 feet southwestward from tidewater near the head of the West Arm of Kendrick Bay. The claims were located by Jack Bowman and Thomas Weston during May 1956 and are in a dense forest that contains only a few outcrops. The workings consist of several small prospect pits and trenches, principally on the No. 1 claim. The largest trench is 12 feet long, 3 feet wide, and from 3 to 5 feet deep. Access is by a trail from the West Arm of Kendrick Bay.

GEOLOGY

Most of the country rock near the Cheri claims is quartz diorite, but subordinate amounts of impure quartzite that is included in the slate unit and a small andesite(?) dike are exposed at the No. 1 prospect. The claims are within the albitized aureole that surrounds the peralkaline granite boss, and the rocks are strongly altered, fractured, and cut by quartz veinlets. The quartzite forms a pendant within the quartz diorite that cannot be accurately delineated because of poor outcrops. Apparently it is small and has a northwesterly trend. Many northeastward-trending quartz veinlets transect the quartzite. Most of the radioactive minerals at the No. 1 prospect occupy the interstices of the impure quartzite, a mode of occurrence that is unique for the area (fig. 24).

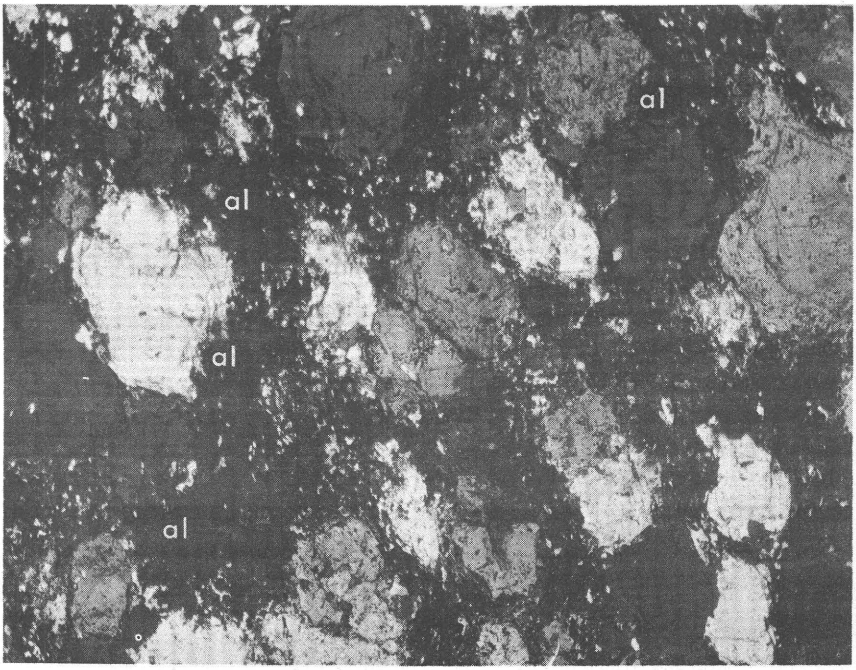


FIGURE 24.—Allanite (al), and possibly other radioactive minerals, associated with abundant hematite in the interstices of impure quartzite. Crossed nicols (× 26).

Allanite is the only radioactive mineral that has been identified. It occurs with abundant hematite and subordinate amounts of albite, quartz, calcite, epidote, and chlorite, principally in the interstices of the quartzite. Lesser quantities of allanite are associated with quartz veinlets elsewhere on the Cheri No. 1 prospect. Most of the other prospects on the Cheri claims are located on quartz veinlets or mineralized fractures that contain minor radioactivity anomalies.

Analyses of radioactive impure quartzite from the Cheri No. 1 prospect are shown in table 8 (No. 56AMK–187). Noteworthy among these analytical results is the high content of both cerium and yttrium subgroup rare earths and the presence of boron.

I AND L PROSPECTS

INTRODUCTION

The I and L prospects are on five claims that were staked by L. A. and Irma Hollenbeak of Ketchikan during the summer of 1955. Several of the initial discoveries were made by prospecting with an airborne Geiger counter. The I and L Nos. 1 and 2 claims adjoin and are on the northwestern flank of Bokan Mountain. The main prospect on the I and L No. 1 claim is 5,300 feet N. 69° W. of Bokan Mountain at an altitude of about 700 feet, and the discovery prospect at the I and L No. 2 claim is 5,500 feet N. 71° W. of Bokan Mountain at an altitude of about 730 feet. Both of these prospects are accessible from the South Arm of Moira Sound although no well-defined trails lead to them. They can also be reached by hiking over fairly steep but open terrain from the Ross-Adams mine.

The workings at the No. 1 prospect consist of a small cut in a fault-controlled ravine (fig. 25). The workings at the No. 2 prospect consist of a shallow trench about 12 feet long and between 2 and 4 feet wide.

The Nos. 3, 4, and 5 claims adjoin and are on the southeastern flank of Bokan Mountain. The main workings on the No. 3 claim are about 4,300 feet S. 79° E. of Bokan Mountain at an altitude of about 1,140 feet; those of the No. 4 claim are 4,100 feet S. 81° E. of Bokan Mountain at altitudes near 1,175 feet; and the few workings on the No. 5 claim are 3,850 feet S. 85° E. of Bokan Mountain at altitudes near 1,375 feet.

Most exploration work has been done on the Nos. 3 and 4 claims, and consists of numerous trenches and prospect pits. For convenience in describing them, five of the trenches are informally designated A, B, C, D, and E (pl. 4).

The principal workings on the No. 3 claims are trenches A and B and small prospect pits nearby (pl. 4). Trench A is 45 feet long, a maximum of 8 feet wide, and 3–4 feet deep, and trends almost due east. Trench B is 53 feet long, about 6 feet in maximum width, and 3–4 feet deep and trends N. 60° W. Trenches C, D, and E constitute most of the small workings at the No. 4 prospect. A few small prospect pits are the only workings on the No. 5 claim.

Access to the I and L Nos. 3, 4, and 5 prospects is by a tractor road from near the summit of the Ross-Adams mine road or by trail from the Ross-Adams mine.

GEOLOGY

All of the I and L prospects are within the peralkaline granite boss near its margin. They are probably genetically linked with late-stage emanations from the peralkaline granite residuum. Some of the deposits are partly syngenetic in pegmatites but most of these pegmatites have also been acted upon by later hydrothermal solutions causing strong argillic alteration and enrichment in iron, uranium, and thorium rare earths, and niobium. In most places the hydrothermal activity has formed most of the radioactive and potential ore minerals.

The radioactive minerals at the I and L No. 1 prospect are localized in altered peralkaline granite adjacent to the hanging wall of a strong fault that strikes N. 14° W. and dips 80° SW. (fig. 25). The alteration is dominantly argillic, but it also involves hydrous iron sesquioxides that have imparted various shades of brown to the altered rocks. It is most intense next to the fault and diminishes outward from the fault over a thickness of about 5 feet to fresh peralkaline granite. The uranium and thorium minerals are associated with the intensely altered rock near the hanging wall of the fault as indicated by the distribution of the anomalous radioactivity shown in figure 25. Subordinate amounts of slightly altered peralkaline granite are irregularly distributed along several strong joints that parallel the fault, but only small amounts of radioactive minerals accompany this less intense alteration. Three parallel pegmatite dikes ranging from 3 to 6 inches in thickness that strike N. 55° W. and dip 70° NE. are exposed in the east wall of the No. 1 cut. No radioactive minerals were found in these pegmatite dikes. The ore-controlling fault is poorly exposed away from the No. 1 cut, and, except at the prospect, it has not been explored.

A grab sample representative of the highest grade ore at the No. 1 prospect contained 0.50 percent chemical uranium, 0.54 percent equivalent uranium, and 3.16 percent thorium oxide (table 9, No. 56AMK–201). These analytical results indicate a strong disequilibrium between the uranium and thorium and their daughter products. The results of a semiquantitative spectrographic analysis of

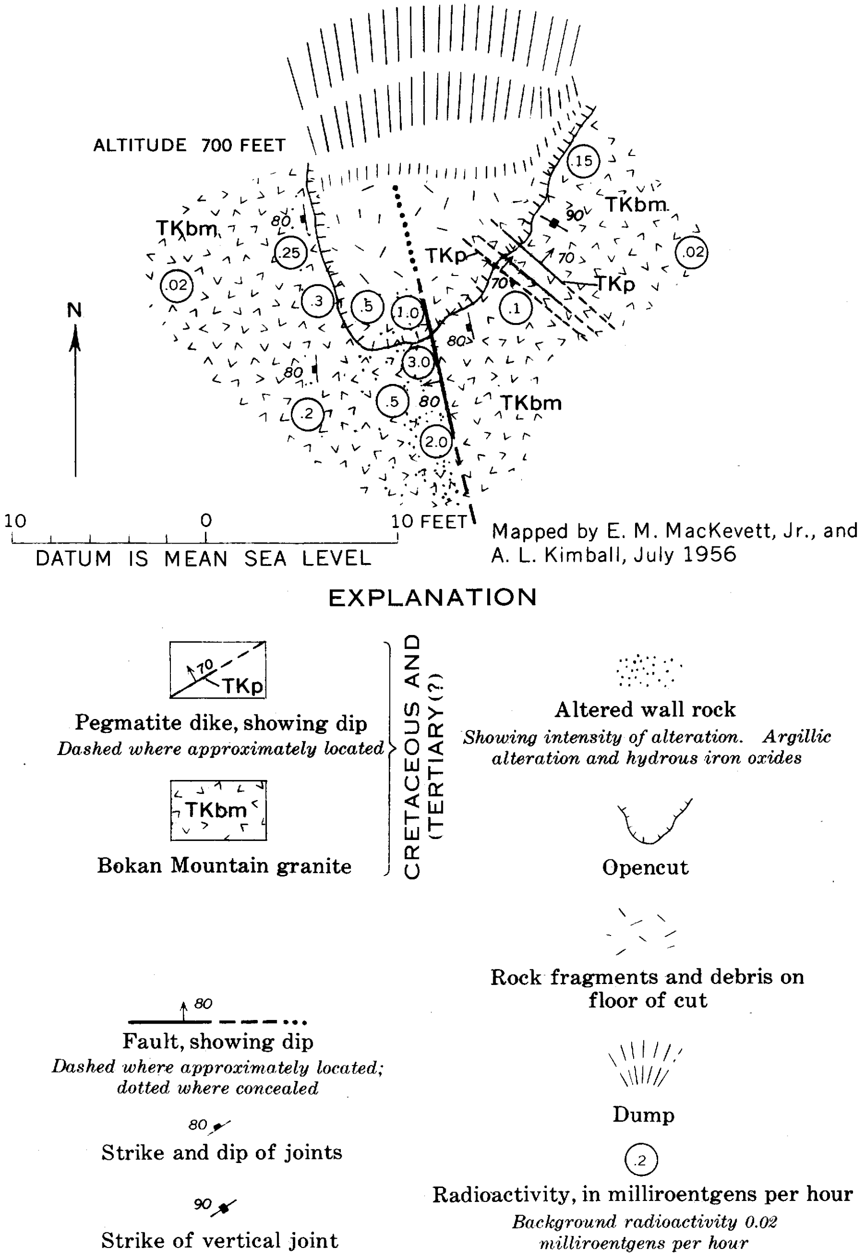


FIGURE 25.—Geologic sketch map of the I and L No. 1 prospect.

this sample, which are also shown in table 9, indicate a fairly high content of some of the rare-earth elements. The ore minerals at the No. 1 prospect have not been identified, but they probably are thorium-rich species such as uranothorite or uranoan thorianite.

The I and L No. 2 prospect is on two parallel pegmatite dikes that cut the peralkaline granite. The dikes range from 2 to 6 inches in thickness and are separated by about 3 feet of peralkaline granite. They strike N. 62° W. and are vertical. The dikes are quartz rich, but they contain a few opaque minerals and relict feldspars that have been largely altered to clay minerals. Steep longitudinal fractures in the dikes probably were conduits for hydrothermal solutions that altered the dikes and the peralkaline granite within a few feet of the dikes. The alteration is largely manifested by clay minerals, hydrous iron oxides, and questionably by manganese minerals, and most of the altered rocks are light brown, reddish brown, or maroon. Minor amounts of purple fluorite and pyrite are associated with some of the altered rocks. The alteration is less intense than that at the No. 1 prospect, and instead of pervading the adjacent country rock, it is largely confined to within a few inches of fractures in the wall rock.

The maximum radioactivity detected at the No. 2 prospect was 0.3 mr per hr against a background of 0.02 mr per hr, considerably less than that at the No. 1 prospect. No radioactive minerals were identified from the prospect. Analyses of a sample of the radioactive quartz-rich pegmatite are shown in table 9 (No. 56 AMK–200A).

Most of the known occurrences of radioactive minerals at the I and L prospects are at the No. 3 prospects where the fine-grained border facies of the peralkaline granite has been intruded by pegmatite dikes. Hydrothermal solutions followed fractures in the pegmatites, forming veinlets in the pegmatites and peralkaline granite, and altering these rocks. The alteration products are mainly clay minerals, but they include lesser amounts of hydrous iron oxides.

The pegmatites at the I and L No. 3 prospect attain a maximum thickness of about 4 feet, but typically they range from a few inches to 1 foot in thickness. Most of them dip steeply and form a series of subparallel dikes that strike between N. 60° W. and west. Only a few of the pegmatites can be traced for more than 100 feet, which is in part due to poor outcrops but chiefly reflects their lack of continuity. Many pegmatites contain quartz-rich pods or lenses as much as 25 feet long, and some have fine-grained aplitic parts that are difficult to distinguish from some of the altered peralkaline granite. The pegmatites consist chiefly of quartz, but they also contain K-feldspar and albite, both altered, minor amounts of zircon, xenotime, and sphene, and scattered opaque minerals including ilmenite(?), magnetite, and some radioactive minerals. Clay minerals and hydrous iron oxides accompanied by minor amounts of sericite and chlorite are the alteration products. Most of the pegmatite dikes are strongly fractured and are cut by numerous veinlets.

Although some of the radioactive minerals are syngenetic in the pegmatites, a large part of them are associated with the subsequent hydrothermal phase and are found in veinlets both in the pegmatite dikes and in the adjacent altered peralkaline granite. The veinlets are quartz rich and contain moderate quantities of hematite and minor amounts of radioactive minerals, calcite, purple fluorite, pyrite, chlorite, and galena. Radioactive minerals from the No. 3 prospect include uraninite, uranothorite, uranoan thorianite(?), brannerite, ellsworthite, an unidentified metamict niobate(?), and secondary uranium minerals, chiefly beta-uranophane.[2] The chief carriers of the rare-earth elements are parisite, which was identified by both X-ray diffraction and oil immersion methods, xenotime, and bastnaesite, which was questionably identified.

Plate 4 is a geologic map of A and B trenches and nearby pits that also shows the results of a radiometric survey and the locations of samples.

Analyses of 17 radioactive samples from the I and L claims are shown in table 9. The sample locations and other pertinent data are designated under remarks, and locations of the samples from the Nos. 3 and 4 prospects are shown on plate 4.

The I and L deposits are richer in silica than most of the other uranium-thorium deposits in the area. Their dominant alkali metal is sodium, and potassium was reported from only a few of the samples. This situation occurs at several other deposits in the area, notably the Ross-Adams deposit, and indicates that the sodium-rich fluids that promoted albitization are probably related to the ore-forming fluids. Besides containing the suite of minor elements that occurs in most deposits associated with the peralkaline granite, parts of the I and L No. 3 deposits are fairly rich in niobium. Some of the uraninite from pegmatite dikes at the I and L No. 3 prospects yielded excellent X-ray diffraction patterns without heating, whereas most other uraninite from the area is partly metamict and will not yield good X-ray diffraction patterns unless heated.

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[2] The brannerite was identified by Jerome Stone (written communication, 1957) using X-ray diffraction. The other minerals were identified by the writer using X-ray diffraction, X-ray fluorescence, or oil immersion methods.

TABLE 9.—*Semiquantitative spectrographic analyses, equivalent and chemical uranium analyses, and three thorium analyses of radioactive samples from the I and L prospects*

[Semiquantitative spectrographic analyses by Joseph Haffty, U.S. Geol. Survey. Values for spectrographic analyses in percent to the nearest number in the series, much greater than 10, 10, 3, 1, 0.3, 0.1, 0.003, 0.001. Standard sensitivities for the elements sought in the semiquantitative spectrographic analyses are shown in table 11. Dashes indicate not detected]

Sample	Remarks	Percent—			Ag	Al	Ba	Be	Ca
		cU [1]	eU [2]	Th					
56AMK-89+0	Chip sample, trench A, I and L, No. 3.	0.17	0.14	(3)	<0.001	3	0.03	0.001	0.03
89+10	do.	.95	.93	(3)	<.001	3	.01	.001	.03
89+20	do.	.26	.18	[4]0.11	<.001	3	0.003	.001	.03
89+30	do.	.013	.017	(3)	------	3	------	.001	.1
93+0	Chip sample, trench B, I and L, No. 3.	.26	.27	(3)	<.001	3	.01	.001	.03
93+10	do.	.060	.060	(3)	<.001	1	.003	.001	.03
93+20	do.	.046	.060	(3)	------	3	.003	.001	.03
93+30	do.	.010	.12	(3)	<.001	3	.001	.01	.03
93+40	do.	.026	.032	(3)	------	3	.003	.01	.03
93+50	do.	.026	.042	(3)	------	3	.01	.001	.03
96	Selected specimen, trench B, I and L, No. 3.	.21	.30	(3)	<.001	1	<.001	.003	1
97	Selected specimen from small pit west of trench A, I and L, No. 3.	.26	.26	[4].024	------	3	.003	.03	.1
103	Chip sample, trench C, I and L, No. 4.	.14	.20	(3)	<.001	3	.01	.001	.01
107	Chip sample, trench D, I and L, No. 4.	.18	.35	[4].36	<.001	3	.003	.001	.01
108	Chip sample, trench E, I and L, No. 4.	.060	.14	(3)	<.001	3	.01	.003	.03
200A	Grab sample from quartz-rich pegmatite, I and L, No. 2	.003	.010	(3)	------	0.3	.001	------	.003
201	Grab sample, I and L, No. 1.	.50	.54	[5]2.76	<.001	10	.01	<.001	.03

Sample	Ce	Cr	Cu	Dy	Er	Fe	Ga	Gd	Hf	Ho
56AMK-89+0	------	0.001	0.003	------	------	3	0.003	------	------	------
89+10	0.3	.003	.003	0.01	0.03	3	.003	------	0.03	------
89+20	.03	.003	.003	------	.01	3	.003	------	------	------
89+30	------	.003	.003	------	------	3	.003	------	------	------
93+0	.1	.003	.001	.01	.03	1	.003	------	.01	------
93+10	------	.003	.003	------	------	3	.003	------	------	------
93+20	------	.003	.003	------	------	1	.003	------	------	------
93+30	------	.001	.001	------	------	1	.003	------	------	------
93+40	------	.001	.001	------	------	1	.003	------	------	------
93+50	------	.003	.001	------	------	1	.003	------	------	------
96	.3	.001	.003	.01	.01	1	<.001	0.01	------	------
97	.3	.001	.001	.3	.3	1	.003	.1	------	0.1
103	------	.001	.003	------	.01	3	.003	------	------	------
107	------	.001	.003	.03	.03	3	.003	------	------	------
108	.1	.001	.003	.03	.03	3	.003	------	------	------
200A	------	.001	.003	------	------	3	------	------	------	------
201	.3	.003	.003	.1	.1	10	.003	.03	------	.003

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[1] Chemical uranium analyses by Rossevelt Moore, U.S. Geol. Survey.
[2] Radiometric analyses by B. A. McCall, U.S. Geol. Survey.
[3] Not analyzed for thorium except by semiquantitative spectrographic methods.
[4] Chemical analysis for thorium by Esma Campbell, U.S. Geol. Survey.
[5] X-ray fluorescence analysis for thorium by Isidore Adler, U.S. Geol. Survey.

TABLE 9.—*Semiquantitative spectrographic analyses, equivalent and chemical uranium analyses, and three thorium analyses of radioactive samples from the I and L prospects*—Continued

Sample	K	La	Li	Lu	Mg	Mn	Mo	Na	Nb	Nd	Ni
56AMK-89+0	------	------	------	------	0.03	0.03	------	3	0.3	------	------
89+10	------	0.03	------	------	.03	.03	------	3	1	0.01	------
89+20	------	.01	------	------	.03	.01	------	3	.3	------	------
89+30	1	------	------	------	.1	.03	------	3	.03	------	------
93+0	.3	.01	------	------	.01	.03	------	3	.3	.01	------
93+10	------	------	------	------	.01	.01	------	3	.3	------	0.003
93+20	------	.01	------	------	.03	.01	------	3	.03	.01	------
93+30	------	------	------	------	.03	.01	------	3	.03	------	------
93+40	1	------	------	------	.01	.01	------	3	.03	------	------
93+50	------	------	0.01	------	.3	.01	------	3	.01	------	------
96	------	.1	------	------	.01	.01	------	.3	.03	.03	.003
97	------	.03	.003	0.1	.03	.03	0.003	3	.01	.03	------
103	------	------	------	------	.03	.03	.003	3	.03	------	.003
107	------	------	------	------	.03	.01	.003	3	.03	------	.003
108	------	.03	------	------	.1	.03	------	3	.03	.03	.003
200A	------	------	------	------	.001	.01	------	.1	------	------	.001
201	3	.01	------	------	.01	.03	.003	3	------	.03	------

Sample	Pb	Sc	Si	Sn	Sr	Th	Ti	U	Y	Yb	Zr
56AMK-89+0	0.1	------	(6)	0.01	0.001	------	0.1	0.1	0.01	0.001	0.03
89+10	.1	0.001	(6)	.03	.01	0.1	.3	1	.1	.03	1
89+20	.03	.001	(6)	.03	.001	.1	.1	.3	.03	.001	.1
89+30	.01	.001	(6)	.01	.003	------	.1	------	.003	.001	.03
93+0	.03	------	(6)	.01	.003	.1	.1	.3	.1	.01	.3
93+10	.03	------	(6)	.01	.001	.03	.1	------	.003	.001	.03
93+20	.01	------	(6)	.01	.001	.1	.1	------	.003	.001	.03
93+30	.01	------	(6)	------	------	.1	.03	------	.01	.001	.1
93+40	.001	------	(6)	.003	------	.03	.03	------	.003	.001	.03
93+50	.003	------	(6)	.003	.001	.1	.1	------	.01	<.001	.01
96	.1	.001	(6)	.003	.003	.1	.03	.1	.03	.003	.03
97	.003	------	(6)	------	.003	------	.3	.3	1	.1	.01
103	.01	------	(6)	.001	.001	.3	.1	.3	.03	.01	.3
107	.01	------	(6)	------	.001	.3	.1	.3	.1	.01	.1
108	.003	------	(6)	------	.001	.3	.1	------	.1	.03	.3
200A	.001	------	(6)	------	------	.03	.003	------	.03	.003	.01
201	.01	------	(6)	------	.001	3	.1	.3	.3	.03	.03

[6] Much greater than 10.

The I and L No. 4 prospects occur in an environment similar to the No. 3 prospects that is characterized by a series of quartz-rich pegmatite dikes cutting a border facies of the peralkaline granite (pl. 4). The pegmatite dikes strike between N. 60° W. and west and are vertical. Most of the radioactive minerals are in hematite-rich quartz-calcite veinlets in argillized pegmatite and peralkaline granite. A few uranium-thorium minerals form discrete crystals in the pegmatites. Both the veinlets and the alteration minerals were probably formed from hydrothermal solutions that followed fractures in the pegmatites. The suite of radioactive and gangue minerals at the No. 4 prospects and their modes of occurrence are about the same as those at the No. 3 prospect. Analytical result of three chip samples from the I and L No. 4 prospect, including one sample from each of the trenches C, D, and E, are shown in table 9 (Nos. 56AMK–103, –107, –108). The locations of these samples and the distribution of the anomalous radioactivity are shown in plate 4.

The No. 5 prospect is on a series of pegmatite dikes that commonly are less than 1 foot thick and cut the peralkaline granite. Only minor alteration occurs at the No. 5 prospect. The maximum anomalous radioactivity, 0.3 mr per hr against a background of 0.02 mr per hr, is associated with several steep narrow pegmatite dikes that strike N. 10° E. These dikes are offset by a fault that strikes N. 75° W. and dips 60° N. displacing them about 1 foot left laterally. This fault contains a slightly radioactive pegmatite dike about 1 foot thick. Elsewhere on the No. 5 prospect a few radioactive minerals are associated with hydrous iron oxides that are irregularly distributed in a pegmatite dike. Most of the radioactive minerals at the No. 5 prospect are believed to be syngenetic in the pegmatites.

I, L, AND M PROSPECTS

The I, L, and M prospects are on three claims that were located by L. A. and Irma Hollenbeak and Charles Miller during the summer of 1955. The claims are at altitudes between 1,500 and 2,000 feet on a spur that trends eastward from Bokan Mountain. They are a short distance from the Ross-Adams mine, from which they are accessible by hiking over steep bare slopes. Their workings consist of a few shallow pits and trenches.

The prospects are within strongly jointed peralkaline granite that is cut by pegmatite dikes. The I, L, and M No. 1 prospect is on an irregular iron-stained altered zone, as much as 30 feet wide and 200 feet long, in peralkaline granite. This zone is the source of weak anomalous radioactivity.

The No. 2 prospect is on a pegmatite dike about 2 feet thick that is exposed over a length of 50 feet. The dike strikes N. 10° W. and dips 40° NE. It consists chiefly of argillized feldspars and quartz, but it also contains irregularly distributed grains of a radioactive black and minor amounts of hematite. The maximum radioactivity that was detected at this prospect was 3.0 mr per hr against a background radioactivity of 0.03 mr per hr.

Analyses of a selected sample of this radioactive pegmatite are shown in table 8 (No. 57AMK–55).

The No. 3 prospect is on small pegmatite dikes that emit weak anomalous radioactivity. They are probably similar in composition to the pegmatite at the No. 2 prospect but contain less uranium, thorium, and rare earths.

LITTLE JOE AND LITTLE JIM PROSPECTS

The Little Joe and Little Jim prospects are on several claims that were located by Donald Marx during the summer of 1956. The claims are on the northeastern flank of Bokan Mountain at altitudes between 1,000 and 1,750 feet, and the workings consist of a few small prospect pits. No trails lead to the prospects, but they can be reached by hiking northwestward from near the summit of the Ross-Adams mine road over steep but open terrain.

The prospects are on a series of pegmatite dikes that cut the peralkaline granite. The dominant trends of the dikes are N. 65°–75° W. and between N. 15° W. and N. 30° W. The dikes of the first set dip steeply, but those of the second set dip from 35°–50 SW. A few of the pegmatite dikes do not conform to either of these sets and are characterized by diverse attitudes. The dikes are from a few inches to about 2 feet thick and are traceable for a maximum length of about 800 feet. They are rich in quartz and feldspar, and a few of them contain riebeckite and zircon and minor amounts of radioactive blacks that have not been identified. A strong vertical fault that strikes N. 75° W. cuts across the Little Joe and Little Jim claims, but it appears to lack uranium-thorium deposits.

The highest anomalous radioactivity from this group of prospects, 0.9 mr per hr against a background of 0.02 mr per hr, was recorded at the Litttle Jim prospect near the crest of the spur that trends northward from Bokan Mountain. At this prospect uranium-thorium minerals are widely scattered throughout a 2-foot-thick pegmatite dike that strikes N. 70° W. and dips 80° NE. Analyses of a representative sample from this prospect are shown in table 8 (No. 56AMK–166A).

The content of minor elements in this sample is similar to that of many of the pegmatites that are associated with the peralkaline granite. The other radioactive deposits on the Little Joe and Little Jim claims are also mainly formed by scattered uranium- and thorium-bearing minerals that are largely syngenetic in the pegmatite dikes.

LAZO PROSPECTS

The Lazo group of prospects comprises numerous claims that are on the northwestern slope of Bokan Mountain. The claims were located in June 1955 by Herman Ludwigsen, Arnt Antonsen, E. R. Zaugg, and C. A. Olson, all of Ketchikan. The principal workings are on the Old Crow claim, which is 4,350 feet N. 35° W. of Bokan Mountain at an altitude of 1,000 feet, and on the Wennie claims, which are 5,400 feet N. 78° W. of Bokan Mountain at altitudes between 700 and 900 feet. Workings at the Old Crow prospect consist of a small cut and several irregular shallow excavations. The workings at the Wennie prospect consist of several shallow cuts. Similar shallow cuts are on most other prospects of the Lazo group at sites of weakly anomalous radioactivity. No well-defined trails lead to the prospects and access is from the South Arm of Moira Sound through dense forest and muskeg, or by circuitous routes from the Ross-Adams mine.

All the Lazo prospects are within the peralkaline granite boss, and most of them are on steep fractures that chiefly contain reddish-brown to black hydrous iron and manganese (?) oxides.

The Old Crow prospect is on a fault that strikes N. 70° E. and dips 80° NW. The fault zone, about 1 foot thick, contains strongly iron-stained and argillized peralkaline granite that is cut by numerous veinlets that carry quartz, calcite, hematite, fluorite, and minor amounts of radioactive minerals. Veinlets of similar composition penetrate the wallrock for a few feet adjacent to the fault zone. The maximum anomalous radioactivity detected at this prospect was 0.1 mr per hr against a background of 0.02 mr per hr.

At the Wennie prospect the radioactive minerals occur in mineralized zones along fractures and in numerous veinlets adjacent to the fractures. The mineralized zones may be as much as a foot thick and are made up mostly of quartz, clay minerals, and hematite, fairly abundant thorium minerals, and subordinate amounts of pyrite, calcite, fluorite, xenotime, zircon, monazite, and other rare-earth minerals. These minerals are an assemblage that consists of the remnants of the original granite and alteration products from it as well as the minerals introduced by the hydrothermal solutions. Two sets of mineralized fractures are evident: the most important strikes N. 60° W. and dips 80° NE., and the other set strikes east and dips 60° S. These deposits are notably rich in thorium and in rare-earth elements. The thorium is mainly contained in uranothorite and uranoan thorianite and to a lesser extent in monazite. The rare-earth elements are believed to be incorporated in such minerals as monazite, zircon, xenotime, parisite (?), and bastnaesite (?). The latter two minerals were questionably identified from veinlets in altered peralkaline granite near a fracture zone. The maximum anomalous radioactivity that was detected at the Wennie prospect was 5.5 mr per hr with a backgroud of 0.03 mr per hr.

Analyses of a sample of the strongly radioactive material from a fracture zone at the Wennie prospect are shown in table 8 (No. 56AMK–232B).

Notable results of these analyses are the high contents of cerium, dyprosium, erbium, phosphorus, thorium, and yttrium.

The other deposits of the Lazo group also mainly occupy faults and joints within the peralkaline granite. Most of them, however, emit only weak anomalous radioactivity, and none is as rich in thorium and rare earths as the deposits on the Wennie claims.

BOOTS PROSPECT

The Boots prospect is on claims that were located by O. H. Newlun of Ketchikan during July 1956. It is about 3,500 feet S. 28° E. of the mouth of Perkins Creek at an altitude of about 850 feet. Access is by hiking through a dense forest from the South Arm of Moira Sound. The only workings at the prospect are a few shallow surface pits.

A dikelike mass of aplite is the country rock at the Boots prospect. The aplite is cut by several pegmatite dikes, which are as much as 1 foot thick and traceable for about 150 feet. The weak anomalous radioactivity that was detected at this prospect is from radioactive minerals that are sparsely disseminated in the pegmatites or are minor constituents of small irregular iron-stained and argillized masses of pegmatite and aplite.

The pegmatites consist chiefly of quartz and K-feldspar with lesser amounts of albite, biotite, clay minerals, and secondary iron oxides. They are noteworthy in that they are among the few pegmatites related to the peralkaline granite that contain mica.

Although no radioactive minerals were identified at the prospect, the anomalous radioactivity apparently is produced in part from minerals that were introduced by hydrothermal processes and deposited in veinlets, and in part from minerals indigenous to the pegmatites. The maximum anomalous radioactivity detected at the Boots prospect was 0.4 mr per hr against a background of 0.02 mr per hr.

Analyses of a sample of the radioactive aplite that contains abundant hematite and clay minerals are shown in table 8 (No. 56AMK–229A).

GEIGER PROSPECT

The Geiger prospect is on the south shore of the South Arm of Moira Sound about 2,900 feet northeast of the mouth of Perkins Creek. The prospect is about 20 feet landward from, and a few feet higher than, the high-tide mark and is readily accessible by boat. It was located by R. L. Lee of Ketchikan in April 1956, and its workings are a few small pits.

The prospect is on an altered felsic dike, probably originally rhyolite or quartz latite, that cuts Devonian(?) metavolcanic rocks. The dike is 6 feet thick and strikes N. 35° W. and dips 85° SW. It is a very fine grained rock that contains abundant quartz and less K-feldspar, albite, zircon, and clay minerals. Much of its K-feldspar is microperthitic and is rich in exsolved albite. The wallrocks are albitized locally. The radioactive minerals are in veinlets that occupy fractures in the dike and are associated with quartz, pyrite, fluorite, and hydrous iron oxides.

No radioactive minerals were identified from the prospect. The maximum anomalous radioactivity that was detected was 0.3 mr per hr against a background radioactivity of 0.015 mr per hr. Analyses of a sample of the radioactive dike are shown in table 8 (No. 56AMK-236B).

PIEPER'S PURPLE PROSPECTS

The Pieper's Purple prospects are about 3,250 feet due south of Bokan Mountain at altitudes between 1,500 and 1,700 feet. They were located by Paul Pieper and associates during the summer of 1955, and their workings consist of a few shallow pits and trenches. They are accessible by hiking from the Ross-Adams mine.

The Pieper's Purple prospects were located with the intent of recovering both uranium and fluorite. The prospects are on an altered mafic dike that occupies a fault at or near the contact between the peralkaline granite and Devonian(?) slate, or on aplite or pegmatite dikes within the peralkaline granite. They are at sites of weak anomalous radioactivity. Commonly the altered mafic dikes are cut by fluorite-rich veinlets a few millimeters thick that also contain minor amounts of quartz, pyrite, and radioactive minerals. Clay minerals and chlorite are the commonest alteration products in the mafic dikes. The fluorite is dark purple, probably an effect of the radioactive emanations. No radioactive minerals were identified from these prospects.

OTHER PROSPECTS NEAR BOKAN MOUNTAIN

Numerous other uranium-thorium prospects and claims are within the peralkaline granite boss or in the albitized aureole that surrounds the boss. These prospects are not described separately because most of them are at sites that are only weakly radioactive, their workings are scant, and the names and owners of some of them were not ascertained. Like most prospects in the area they are only slightly explored. Their uranium-thorium minerals, in common with most deposits associated with the peralkaline granite, are mainly of hydrothermal origin and occupy veinlets in altered rock in and near faults and fractures, but to a lesser extent some are syngenetic in pegmatite dikes where they form widely scattered, erratically distributed crystals. Hematite, clay minerals, fluorite, quartz, calcite, and pyrite typically accompany the hydrothermal uranium-thorium deposits.

PROSPECTS NEAR GARDNER BAY

Several small prospect pits have been excavated along the shores of Gardner Bay, particularly adjacent to the salt chuck near the southern entrance to the bay. These prospects are on pegmatite dikes and lenses that are as much as 2 feet thick. The dikes, which cut diorite or quartz diorite, have diverse strikes and mainly dip steeply, but a few of them dip at angles as low as 20° or 30°. Most of the dikes cannot be traced for more than 50 feet, and many form lenses or podlike masses that are less than 20 feet long. The pegmatite dikes consist mainly of very coarse grained pink perthite crystals and quartz, but they contain small quantities of oligoclase, biotite, magnetite, and very sparsely distributed unidentified "radioactive blacks." The widely scattered radioactive minerals that are the sources of the weak anomalous radioactivity are primary to the pegmatites. These dikes are deficient in the rare earths and many other minor elements that characterize the pegmatites affiliated with the Bokan Mountain granite.

PROSPECTS NEAR STONE ROCK BAY

The prospects near Stone Rock Bay are on several claims that are located on the headland between Stone Rock Bay and Mallard Bay. The prospects are on claims that were staked by W. C. Smith of Ketchikan, and their workings consist of a few shallow pits.

Syenite is the country rock near the prospects, but most of the radioactive occurrences are in altered andesite(?) dikes that cut the syenite. The andesite(?) has been altered largely to masses of chlorite and clay minerals, but it contains minor relicts of plagioclase and pyroxene. It is strongly fractured and cut by numerous veinlets that in places form reticulating networks. Two types of veinlets are discernible under the microscope. The oldest veinlets are rich in quartz and hematite and contain subordinate amounts of radioactive minerals. These veinlets are cut by calcite veinlets that lack radioactive minerals. The maximum anomalous radioactivity detected was about 10 times the background. Monazite was questionably identified from these prospects, and it probably is their chief radioactive mineral.

COPPER AND GOLD DEPOSITS

The copper and gold deposits are largely between McLean Arm and Mallard Bay and are on numerous claims that were staked during the early 1900's. The earliest mention of mining activity in the Bokan Mountain area was by Wright (1909, p. 83), who briefly described the copper prospects south of McLean Arm and those near Mallard Bay. Since then a few short summaries of mining activities at the copper and gold prospects have appeared in U.S. Geological Survey publications. These include descriptions of the Veta prospect by Knopf (1910, 1911), and of the known copper-gold deposits in the area by Smith (1914), and Chapin (1916, 1917).

The most extensive workings are on the Polson and Ickis group of claims, which lie south of the medial parts of McLean Arm. Less extensive workings are about a thousand feet west of the head of Mallard Bay at a prospect whose name is not known with certainty, although it probably is the Veta. Both the Polson and Ickis and the Veta are primarily copper prospects, although their gold values locally exceed their copper values.

The Nelson and Tift gold mine and the gold prospect near the head of the South Arm of Moira Sound were explored subsequent to the heyday of copper prospecting. A few other small prospect pits were found, but are now largely covered with vegetation or sloughed in. Most of these workings were probably made in search of copper or gold, but in many instances the sought commodity could not be determined.

No comprehensive studies were made of the copper and gold deposits, although most of the accessible prospects were mapped and an endeavor was made to determine their geologic setting. Descriptions of the prospects are supplemented by published reports and by unpublished data compiled by the State of Alaska Division of Mines and Minerals.

COPPER AND GOLD PROSPECTS

POLSON AND ICKIS PROSPECTS

The Polson and Ickis prospects are on numerous claims south of the medial parts of McLean Arm at altitudes between 100 and 1,000 feet. Their workings include many shallow pits and trenches, three adits, and several surface cuts. The No. 1 adit (pl. 5) trends southward for about 280 feet from its portal, which is at an altitude of 330 feet. It connects with a total of nearly 60 feet of short subsidiary drifts and crosscuts. The No. 2 adit trends S. 25° W. from its portal, which is at an altitude of 450 feet, and extends for about 60 feet (pl. 5). The No. 3 adit is at an altitude of 540 feet and trends S. 75° E. for 12 feet. An opencut about 75 feet long trends S. 55° E. from a point 250 feet north of the No. 3 adit at an altitude of 400 feet. The Wano opencut is at the site of recent exploration on the Wano claim, about 800 feet N. 50° W. of the portal of the No. 1 adit at an altitude of 190 feet (pl. 5). Another opencut about 30 feet long trends S. 23° W. from a point 300 feet S. 82° E. of the No. 2 adit portal at an altitude of 450 feet. The Polson and Ickis prospects are accessible by a good trail from the Polson and Ickis millsite on the south shore of McLean Arm.

GEOLOGY

The Polson and Ickis prospects are in an area that is largely underlain by monzonite that locally grades into syenite. Quartz diorite and diorite containing local fine-grained facies that have been called "greenstone" (Chapin, 1917, p. 66), and a few diabase dikes are exposed at some of the prospects. Granodiorite and pyroxenite crop out within the limits of the claims but not at any of the prospects.

The monzonite is a medium-grained rock that consists of nearly equal amounts of sodic andesine and microperthitic K-feldspar. Minor accessory minerals of the monzonite are xenotime, apatite, and magnetite, and the secondary minerals are sericte and clay minerals.

The ore minerals are localized in quartz-calcite-barite veins that are in a series of steep fault zones that range in strike from north to N. 25° E. Besides the nonmetallic gangue minerals, the deposits contain fairly abundant pyrite and hydrous iron oxides, minor amounts of chalcopyrite, hematite, and chrysocolla, and very small but detectable amounts of bornite and gold. To a lesser extent the ore minerals form in veinlets in the adjacent wallrock. The veins have been displaced and locally shattered by post-ore faulting, which largely accounts for their discontinuity. Fairly intense argillic alteration has pervaded the wall rock for several feet near the veins.

The No. 1 adit was driven along a fault zone striking from north to N. 15° E. (pl. 5). The fault zone is as much as 8 feet thick, and although some fractures within it dip as little as 45° SE., most dip between 70° and 80° SE. The fault zone contains abundant breccia and gouge and is interlaced with veins that are as much as 1 foot thick. The workings are mainly within the monzonite that is extensively argillized. A vertical diabase dike, 14 feet thick and trending nearly east, and another dike 2 feet thick and having a similar attitude, are exposed underground on the east side of the fault about 160 feet from the portal. These dikes probably correlate with a poorly exposed diabase dike in a gully about 100 feet west of the adit. If this correlation is valid the strike-slip component on the fault is 40 or 50 feet and right lateral.

The veins consist chiefly of quartz, calcite, and barite with moderate quantities of disseminated pyrite. Minor amounts of chalcopyrite locally rim and cut the pyrite grains. Chrysocolla, specular hematite, and hydrous iron oxides are less abundant constituents of the veins.

Two samples of vein material from the No. 1 adit were analyzed with an X-ray fluorescence spectrometer. They yielded strong copper and iron peaks and a nickel peak slightly larger than that inherent in the X-ray system. The tenor of the ore is shown by the assay data that accompany plate 5. The assays were made by the Territorial Department of Mines (now State of Alaska Division of Mines and Minerals) and these data are published with permission of the mine owners.

The No. 2 adit is on a fault zone that strikes N. 25 E. and dips between 75° and 85° SE. (pl. 5). It is in monzonite that it is strongly argillized and cut by veinlets. The ore minerals are within discontinuous quartz-rich veins within the fault zone, and to a lesser extent in veinlets in the adjacent wall rock and are thus very similar to occurrences in No. 1 adit. The ore minerals are chalcopyrite, bornite, chrysocolla, and gold that are associated in minor amounts with disseminated pyrite in the veins and veinlets. The veins also contain calcite, subordinate quantities of barite, and secondary iron minerals. The results of assays for copper and gold, which were made by personnel of the Territorial Department of Mines, accompany plate 5 and are published with the permission of the mine owners.

The short southeastward-trending adit at the No. 3 prospect is a crosscut that penetrates a northeastward-trending fault near its face, which contains abundant gouge and breccia. This is probably a strand of the fault zone exposed in the No. 1 adit. It strikes N. 20° E. and dips 65° NW., but its thickness could not be determined. The adit is within partly altered monzonite. The fault contains veins similar in composition to those exposed in the other adits. In places secondary minerals, principally chrysocolla and hydrous iron oxides, form coatings on breccia fragments and gouge surfaces within the fault.

Irregular copper- and iron-bearing veins are exposed in a steep northeastward-trending fault that cuts monzonite at the opencut about 250 feet north of the No. 3 adit. These veins carry abundant barite, moderate amounts of quartz and calcite, and minor amounts of pyrite, chalcopyrite, specular hematite, secondary copper minerals, and "limonite." A sample from this cut was analyzed by X-ray fluorescence spectrometer, which showed it to have a high iron content and a moderate copper content.

The Wano opencut (pl. 5) is within a salient of monzonite about 45 feet thick that is bounded by fine-grained diorite or "greenstone." The monzonite is bordered on the east by a fault that strikes N. 2° W. and dips 60° NE. Along its western contact it intrudes fine-grained diorite. The principal structure at this prospect is a fault zone about 5 feet thick that strikes N. 25° E. and dips 70° SE. This zone is sheared and brecciated and contains numerous veins. The sulfide minerals, chiefly pyrite with subordinate chalcopyrite, occur in the veins or are distributed in veinlets or disseminations in the altered monzonite, mainly near faults. Only minor quantities of pyrite and chalcopyrite have formed in the diorite. The monzonite is more extensively altered at this prospect than elsewhere and it has been locally silicified and sericitized rather than argillized. Some of the monzonite has been partly replaced by masses of calcite crystals 3 or 4 mm long that have subsequently been deformed and fractured. This replacement apparently followed the influx of silica, as calcite locally cuts and surrounds quartz that has been introduced. Pyrite that is rimmed and veined by subordinate amounts of chalcopyrite forms disseminations at boundaries between quartz and calcite, or veinlets that cut quartz and calcite. Only a few relicts of primary minerals of the monzonite, mainly altered feldspars, remain in the intensely altered rock.

An X–ray spectrometer analysis of a sample from this prospect showed moderately abundant iron, copper, and calcium.

The cut near the No. 2 adit is within monzonite and exposes a steep fault zone about 6 feet wide that strikes N. 23° E. and dips 80° SE. Banded veins a few inches thick that contain pyrite, chalcopyrite, and bornite in a quartz- and calcite-rich gangue occur in the fault zone, and the sulfides are also disseminated in minor amounts in the adjacent strongly altered wall rock.

VETA PROSPECT

The Veta prospect is about 1,000 feet N. 70° W. of the head of Mallard Bay at altitudes between 125 and 150 feet. It is readily accessible by a good trail from the head of Mallard Bay. The workings consist of two caved vertical shafts and other inaccessible underground workings. Knopf (1910, p. 143) reports that one of the shafts was 30 feet deep, and that 78 feet of drifts and crosscuts had been driven from it.

The workings explore a strong fault that strikes N. 50° W. and dips 80° NE. in altered fine-grained diorite or greenstone. The fault contains a mineralized zone about 3 feet wide, which is pervaded by brown secondary iron minerals. Clay minerals are also abundant throughout this zone and in the nearby wallrock. The veins within the mineralized zone are rich in quartz and locally contain pyrite and chalcopyrite, and lesser quantities of bornite, malachite(?), chrysocolla, and specular hematite. Sulfides are also sparsely disseminated throughout the sheared and intensely altered diorite within the mineralized zone.

OTHER COPPER DEPOSITS

Small quantities of copper minerals were found at several other places in the area. They occur in some of the quartz-calcite-pyrite veins and altered aplite dikes in the southern part of the area, principally near Stone Rock Bay, and they also constitute subordinate amounts of the small lenselike masses of pyrite within schist on the Kendrick Islands.

GOLD MINES AND PROSPECTS

NELSON AND TIFT MINE

The Nelson and Tift mine is on the north shore about 4,000 feet west of the mouth of McLean Arm. The property, which is readily accessible by boat, consists of 10 lode claims and a millsite. Much of the data on this mine is abstracted from unpublished reports by J. C. Roehm of the Territorial Department of Mines (now State of Alaska Division of Mines and Minerals) that were written in 1936 and 1938. The mine is also briefly mentioned by Smith in several U.S. Geological Survey bulletins (1938, p. 18, 19; 1939, p. 21; 1941 p. 20; 1942, p. 21).

Nelson and Tift, two commercial fishermen from Ketchikan, discovered the deposit in the fall of 1935. Late in 1935 the discoverers shipped 2,156 pounds of massive sulfides from the deposit to the Tacoma smelter. This shipment yielded 0.73 ounces per ton in gold and 0.05 ounces per ton in silver. Subsequently about 1,300 tons of ore were mined and shipped to the smelter.

Workings on the property consist of an opencut and several small pits and trenches. The opencut occupies a natural depression, and its limits are difficult to determine accurately. The pits and trenches are badly sloughed and overgrown with vegetation. During 1936, four diamond-drill holes, as deep as 90 feet, were drilled. No ore, however, was cut by any of these drill holes.

The ore consisted largely of auriferous pyrite that formed a lens that was 75 feet long, 30 feet deep, and 9 feet wide. Both massive and disseminated pyrite, associated with small amounts of chalcopyrite and bornite, occurred in the lens. The lens has been mined and as far as is known the property has reverted to the public domain. The lens occurred within a steep septum of calcareous rock between 20 and 40 feet wide (pl. 5). The steep bedding in the septum is locally contorted and overturned. The septum consists largely of medium- or coarse-grained marble that has been intruded by quartz diorite. Near the intrusive contacts, parts of the septum have been converted to calc-hornfels. Three steep faults cut the marble, and one of them forms part of the southern boundary of the septum. The marble contains small irregular cherty masses and a few bands of chert 1 or 2 inches thick.

A few pyrite-bearing quartz veins as much as 6 inches thick cut the calcareous rocks near the northern margin of the septum. These veins probably contain small quantities of gold. Pyrite and minor amounts of magnetite are disseminated throughout parts of the marble.

The tenor of the ore that was mined is indicated from assay data that are shown in table 10.

PROSPECT NEAR THE HEAD OF THE SOUTH ARM OF MOIRA SOUND

A small gold prospect is located a few feet above the high-tide mark on the east bank of a northwestward-trending estuary at the head of the South Arm of Moira Sound. This prospect consists of a narrow cut about 8 feet long. It is on a subsidiary fault that strikes N. 16° E. and dips 85° SE., within highly fractured siliceous metavolcanic rocks. A major northward-trending fault zone is about 200 feet west of the prospect, and fractures related to this fault zone apparently controlled the formation of the estuary that borders the prospect. The nearby Devonian(?) metavolcanic rocks are probably quartz keratophyre or rhyolite in composition.

TABLE 10.—*Assay results of seven channel samples from the Nelson and Tift mine*

[These samples were mainly from the pyrite-rich lens that was mined. The assays were made by the Territorial Department of Mines and accompanied an unpublished report by J. C. Roehm (1936). They are published with the permission of the State of Alaska Division of Mines and Minerals (formerly Territorial Department of Mines)]

Description	Width (in inches)	Ounces per ton	
		Gold	Silver
Massive sulfides, mainly pyrite	35	0. 80	0. 20
Disseminated sulfides in marble	43	1. 24	. 20
Solid sulfides	24	2. 08	. 40
Mineralized marble with some quartz	58	. 12	. 10
Mainly vein quartz	12	1. 06	. 20
Massive sulfides	28	. 92	. 20
Mineralized marble and quartz	61	. 58	. 10

The gold is associated with calcite veins in the northeastward-trending fault and is accompanied by pyrite, chlorite, and secondary iron oxides. The latter have imparted brown stains to the lode and the contiguous host rock. The paucity of the workings indicates that the gold content is too low to encourage much exploration.

IRON DEPOSITS

During the summer of 1958 a subsidiary of the Utah Construction Co. staked several claims for iron in the southern part of the area.

These claims are on two positive magnetic anomalies that were located during an aeromagnetic survey of the southern part of Prince of Wales Island by Rossman and others (1956). The first of these anomalies is centered on a ridge north of the medial parts of McLean Arm at altitudes near 2,200 feet. It is largely caused by magnetite that is associated with hornblende-rich concentrations in diorite and quartz diorite.

The second anomaly is on the spur south of the head of Mallard Bay. It is caused mainly by magnetite that is contained in pyroxenite. The highest magnetite content of any of the thin sections of pyroxenite that were examined during the current investigation was about 10 percent by volume. However, much richer concentrations of magnetite have been found in the pyroxenite by mining company geologists (G. Noel, oral communication, 1959).

DISTRIBUTION OF MINOR ELEMENTS IN THE ROCKS

SCOPE AND LIMITATIONS

This section is an adjunct to the geologic investigations in which the distribution and the role of minor elements in the rocks are discussed. It is based chiefly on semiquantitative spectrographic analyses of large hand specimens and is supplemented by chemical analyses for uranium in each of the samples.

Emphasis is placed on the distribution of the minor elements in the plutonic rocks, which are probably comagmatic, and a relation should exist between the distribution of the minor elements, the rock type, and the position of the rock in the sequence of crystallization. The end members of the plutonic sequence have alkalic affinities and a relatively high minor element content.

This part of the report has several limitations, but none are considered serious enough to impair its general qualitative or semiquantitative value. A more thorough study would be based on more precise analytical data and on more representative sampling. This investigation would also be enhanced by detailed analytical work on individual minerals, such as was done by Wager and Mitchell (1951) on the Skaergaard instrusive rocks, in which the distribution of minor elements could be better correlated with minerals. Such work would be extremely time consuming and is beyond the scope of this paper. Except where the minor elements are essential constituents of a certain mineral, their presumed distribution for the purposes of this report is largely a matter of educated speculation based on such properties as their ionic radii, ionic potential, valence, and their known occurrences as reported in the geologic literature.

The standard sensitivities for the elements sought in the semiquantitative spectrograhpic analyses are shown in table 11. In tables 12–14, which show the results of the semiquantitative spectrographic analyses, only elements that were detected are listed. Undoubtedly many elements occur in the analyzed rocks in quantities too small to detect by the analytical methods that were used. The contents of the major constituents in the samples are also shown in tables 12–14.

MINOR ELEMENTS IN THE METAMORPHIC ROCKS

The analyzed metamorphic rocks comprise three metavolcanic rocks, a slate, a metasiltstone, and two schists (table 12). The metamorphic rocks contain fewer minor elements than the other rocks (tables 13 and 14), and, except for one schist (No. 57AMK–94), they lack the suite of minor elements that characterizes the late crystallates of the plutonic sequence and the hypabyssal rocks that are associated with the peralkaline granite. The highest uranium content of any of the metamorphic rocks was detected in the slate, which also contains a fairly diversified minor element assemblage that is typical of black shale.

TABLE 11.—*Standard sensitivities for the elements determined by the semiquantitative spectrographic methods*

[These sensitivities are realized under ideal conditions, that is, no interferences. Some combinations of elements affect the sensitivity]

Element	Percent	Element	Percent	Element	Percent
Si	0.005	Dy	0.006	Pt	0.003
Al	.0001	Er	.003	[2] Rb	7. (0.007)
Fe	.0008	Eu	.003	Re	.04
Mg	.00003	[1] F	.08	Rh	.004
Ca	.01	Ga	.001	Ru	.008
Na [2]	.01 (0.0003)	Gd	.006	Sb	.01
K [2]	.1 (0.005)	Ge	.001	Sc	.0005
Ti	.0005	Hf	.007	Sn	.001
P	.07	Hg	.08	Sr	.001
Mn	.0007	Ho	.001	Sm	.008
Ag	.00001	In	.0004	Ta	.1
As	.01	Ir	.03	Tb	.01
Au	.001	La	.003	Te	.08
B	.005	[2] Li	.01 (0.00003)	Th	.05
Ba	.0005	Lu	.005	Tl	.04
Be	.00005	Mo	.0005	Tm	.001
Bi	.005	Nb	.001	U	.08
Cd	.005	Nd	.006	V	.001
Ce	.03	Ni	.001	W	.05
Co	.001	Os	.1	Y	.001
Cr	.0006	Pb	.001	Yb	.0001
Cs [2]	.8 (0.01)	Pd	.003	Zn	.008
Cu	.00005	Pr	.01	Zr	.0008

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[1] A separate exposure is required for the fluorine estimation.

[2] A different exposure in the red part of the spectrum is required for the sensitivities shown in parentheses.

TABLE 12.—*Semiquantitative spectrographic analyses and equivalent and chemical uranium analyses of the metamorphic rocks*

[Semiquantitative spectrographic analyses by Joseph Haffty, C. L. Waring, and H. Worthing, U.S. Geol. Survey. Values for spectrographic analyses in percent to the nearest number in the series, much greater than 10, 10, 3, 1, 0.3, 0.1, 0.03, 0.01, 0.003, 0.001. Standard sensitivities for the elements sought in the semiquantitative spectrographic analyses are shown in table 11. Dashes indicate not detected]

Sample	Name	Percent—		Ag	Al	B	Ba	Be	Ca	Ce
		cU [1]	eU [2]							
56AMK-238	Meta-quartz keratophyre	0.002	0.003	--------	10	-------	0.03	--------	1	-----
-240	Meta-quartz latite(?)	.001	.002	--------	10	-------	.03	--------	3	-----
-261	Meta-quartz keratophyre	.002	.004	--------	10	-------	.01	--------	1	-----
-113	Chiastolite slate	.004	.004	<0.001	3	0.03	.3	<0.001	.3	-----
-230	Meta-siltstone	.002	.002	<.001	3	-------	.03	--------	3	-----
57AMK-94	Biotite-hornblende schist	<.001	.004	<.001	10	-------	.3	<.001	3	0.01
-97	Hornblendeandesineschist	<.001	<.001	<.001	10	.003	.03	--------	3	-----

Sample	Co	Cr	Cu	Fe	Ga	K	La	Mg	Mn	Mo	Na	Nb
56AMK-238	0.003	0.03	0.001	3	<0.001	1	------	3	0.1	--------	3	--------
-240	.003	.03	.003	3	<.001	3	------	1	.1	--------	1	--------
-261	.001	.001	.001	3	.001	------	------	.3	.03	--------	3	--------
-113	.003	.03	.01	3	.001	1	------	.3	.03	0.003	0.3	--------
-230	--------	.01	.01	3	--------	------	------	1	.3	.001	1	--------
57AMK-94	.001	<.001	.001	3	.003	3	0.01	3	.03	.001	1	<0.001
-97	.003	.003	.003	10	.003	0.3	------	3	.1	.001	1	--------

Sample	Ni	Pb	Sc	Si	Sr	Ti	V	Y	Yb	Zn	Zr
56AMK-238	0.01	--------	0.003	(3)	0.03	0.3	0.003	0.003	<0.001	------	0.01
-240	.003	--------	.01	(3)	.03	.3	.01	.001	<.001	------	.01
-261	.001	--------	.001	(3)	.03	.1	.001	.01	.001	------	.03
-113	.01	0.001	.003	(3)	.03	.3	.03	.003	<.001	0.01	.01
-230	.01	--------	.003	(3)	.03	.1	.01	.003	<.001	------	.03
57AMK-94	.003	.001	.001	(3)	.1	.3	.01	.003	<.001	------	.01
-97	--------	--------	.01	10	.03	.3	.03	.003	<.001	------	.01

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[1] Chemical uranium analyses by Roosevelt Moore and Joseph Budinsky, U.S. Geol. Survey.

[2] Radiometric analyses by B. A. McCall, U.S. Geol. Survey.

[3] Much greater than 10.

MINOR ELEMENTS IN THE PLUTONIC ROCKS

The results of semiquantitative spectrographic analyses and equivalent and chemical uranium analyses of 31 samples of the plutonic rocks are shown in table 13. The analyzed samples are arranged in table 13 more or less in their order of decreasing age, from the older rocks at the top of the table to the younger rocks at the bottom. The samples include a pyroxenite, a gabbro, two albitized diorites, a quartz diorite, three albitized quartz diorites, three granodiorites, a quartz monzonite, three albitized granodiorites, five albitized quartz monzonites, two gneissic quartz monzonites, two syenites, and seven peralkaline granites.

The late crystallates of the Bokan Mountain plutonic sequence, particularly the peralkaline granite, are enriched in the suite of minor elements that is typical of the uranium-thorium deposits of the area. These minor elements, which include rare earths, niobium, uranium and thorium, are also relatively abundant in the pegmatite and aplite dikes that are affiliated with the peralkaline granite.

The distribution and roles of 29 minor elements in the plutonic rocks are summarized. These elements include one alkali metal, three alkaline earth metals, two light elements of group III, three cerium subgroup rare earth elements four yttrium subgroup rare earth elements, six first transition elements, three second transition elements, two metals from subgroups I and II, three elements from subgroups III and IV, and two radioactive elements.

TABLE 13.—*Semiquantitative spectrographic analyses and equivalent and chemical uranium analyses of the plutonic rocks*

[Semiquantitative spectrographic analyses by Joseph Haffty, C. L. Waring, and H. W. Worthing, U.S. Geol. Survey. Values for the spectrographic analyses reported in percent to the nearest number in the series, much greater than 10, 10, 3, 1, 0.3, 0.1, 0.03, 0.01, 0.003, 0.001. Standard sensitivities for the elements sought in the semiquantitative spectrographic analyses are shown in table 11. Dashes indicate not detected]

Sample	Name	Percent		Ag	Al	B	Ba	Be	Ca
		cU [1]	eU [2]						
57AMK-110	Biotite pyroxenite	<0.001	<0.001	<0.001	10	0.003	0.03	--------	3
66B	Hornblende gabbro	<.001	<.001	<.001	(3)	.003	.003	--------	10
25	Hornblende quartz diorite.	.001	.001	<.001	10	.003	.1	<0.001	10
141	Albitized hornblende diorite.	.001	.002	--------	3	-------	.03	--------	3
56AMK-143A	Albitized hornblende diorite.	.003	.003	--------	3	-------	.03	--------	3
132	Albitized quartz diorite	.001	.001	--------	3	-------	.03	<.001	1
57AMK-17	Albitized hornblende quartz diorite.	.001	.001	<.001	10	.003	.03	<.001	10
19	Albitized hornblende quartz diorite.	<.001	<.001	<.001	10	.003	.03	--------	10
20	Hornblende granodiorite	<.001	.001	<.001	(3)	-------	.1	<.001	10
62A	Hornblende granodiorite	.001	.003	<.001	10	.003	.3	<.001	3
21	Granodiorite	<.001	.002	<.001	10	-------	.3	<.001	3
34	Hornblende quartz monzonite.	.001	.001	--------	10	-------	.3	<.001	1
80	Albitized granodiorite	.006	.005	--------	3	-------	.01	--------	.03
56AMK-134	Albitized granodiorite	.003	.003	--------	3	-------	.01	<.001	.3
138	Albitized granodiorite	.003	.002	--------	3	-------	.03	<.001	.3
88	Albitized quartz monzonite.	.010	.009	--------	3	-------	.03	--------	.3
116	Albitized quartz monzonite.	.006	.002	--------	3	-------	.03	.001	.1
124	Albitized quartz monzonite.	.002	.004	--------	3	-------	.03	<.001	.1
140	Albitized quartz monzonite.	.001	.001	--------	3	-------	.03	<.001	.3
151	Albitized quartz monzonite.	.001	.002	--------	3	-------	.03	<.001	.1
57AMK-56	Gneissic quartz monzonite.	<.001	.002	--------	10	-------	.1	<.001	1
62	Gneissic quartz monzonite.	<.001	.001	<.001	10	-------	.1	<.001	1
126	Syenite	.001	.004	<.001	10	-------	.3	<.001	1
131B	Syenite	<.001	.003	<.001	10	-------	1	<.001	1
56AMK-1	Peralkaline granite	.004	.0024	--------	10	-------	.003	<.001	.03
159	Peralkaline granite	.005	.0038	--------	10	-------	.03	.001	.03
168	Peralkaline granite	.005	.0017	--------	10	-------	.003	<.001	.03
219	Peralkaline granite	.005	.003	--------	10	-------	.01	.001	.1
225	Peralkaline granite	.002	.002	--------	3	-------	.001	<.001	.03
233	Peralkaline granite	.020	.005	--------	10	-------	.01	.001	.3
234	Peralkaline granite	.009	.008	--------	10	-------	.01	--------	.01

See footnotes at end of table.

TABLE 13.—*Semiquantitative spectrographic analyses and equivalent and chemical uranium analyses of the plutonic rocks*—Continued

Sample	Ce	Co	Cr	Cu	Dy	Er	Fe	Ga	K	La	Li
57AMK-110	------	0.003	0.1	0.001	------	------	3	0.001	1	------	------
66B	------	.001	------	.001	------	------	3	.003	------	------	------
25	0.01	.003	.03	.001	------	------	10	.003	1	0.01	------
141	------	.003	.01	.01	------	------	3	.001	1	------	------
56AMK-143A	------	.003	<.001	.01	------	------	10	.001	0.3	------	------
132	------	.01	.001	.01	------	------	10	.003	.3	------	------
57AMK-17	------	.003	.001	.003	------	------	10	.003	.1	------	------
19	------	.001	.003	.003	------	------	3	.003	1	------	------
20	.01	<.001	<.001	<.001	------	------	3	.003	1	.01	------
62A	.01	.001	.001	.001	------	------	10	.003	3	.01	------
21	------	.001	.001	.001	------	------	3	.003	1	.003	------
34	------	.001	.001	<.001	------	------	3	.003	1	------	------
80	------	------	.003	.003	------	------	1	.001	------	------	------
56AMK-134	------	.001	.001	.003	------	------	3	.001	------	------	------
138	------	.001	.001	.001	------	------	3	.001	1	------	------
88	------	------	.001	.001	------	------	1	.001	1	------	------
116	------	------	.003	.003	------	------	1	<.001	.3	------	------
124	------	------	.001	<.001	------	------	1	.003	3	------	------
140	------	------	.001	.001	------	------	3	.001	1	------	------
151	------	------	.001	.001	------	------	1	.001	1	------	------
57AMK-56	------	------	<.001	.003	------	------	1	.003	1	.003	------
62	------	------	<.001	<.001	------	------	1	.003	1	.01	------
126	.01	<.001	<.001	.001	------	------	1	.003	10	.01	------
131B	.01	.001	.001	.001	------	------	1	.003	10	.01	------
56AMK-1	.1	------	.003	.003	------	------	3	.01	3	.03	------
159	.03	------	.003	.001	------	------	3	.003	3	.01	------
168	.03	------	.003	.001	------	------	3	.01	3	.01	.003
219	.3	------	.001	.01	0.01	0.01	3	.003	3	.03	------
225	------	------	.001	.001	------	------	3	.001	1	------	------
233	.1	------	.001	.001	.01	.01	3	.001	3	.03	------
234	.1	------	.001	.003	------	------	3	.001	3	.01	------

Sample	Mg	Mn	Mo	Na	Nb	Nd	Ni	Pb	Sc	Si
57AMK-110	10	0.03	<0.001	0.3	------	------	0.03	------	0.001	10
66B	3	.03	<.001	1	------	------	.001	<0.001	.003	(3)
25	3	.1	<.001	3	------	------	.003	<.001	.003	(3)
141	3	.1	------	1	------	------	.01	------	.01	(3)
56AMK-143A	3	.1	------	1	------	------	.001	------	.001	(3)
132	1	.1	------	3	------	------	.001	------	.01	(3)
57AMK-17	3	.1	<.001	1	>0.001	------	.001	.001	.003	(3)
19	3	.1	.001	3	------	------	.001	<.001	.001	(3)
20	1	.1	<.001	3	>.001	------	------	.001	<.001	(3)
62A	3	.1	<.001	3	.003	------	.001	.001	.001	(3)
21	1	.03	<.001	3	------	------	.001	.001	.001	(3)
34	1	.03	<.001	3	------	------	.001	<.001	.001	(3)
80	.1	.01	------	3	------	------	------	.001	------	(3)
56AMK-134	.3	.03	------	3	------	------	------	------	.001	(3)
138	.3	.03	------	3	------	------	------	------	.001	(3)
88	.3	.03	------	3	------	------	------	------	.001	(3)
116	.1	.01	------	1	------	------	------	.001	------	(3)
124	.03	.01	------	3	------	------	------	.001	------	(3)
140	.3	.01	------	3	------	------	------	------	------	(3)
151	.1	.01	------	3	------	------	------	------	.001	(3)
57AMK-56	.3	.03	<.001	3	>.001	------	.001	.001	<.001	(3)
62	.3	.03	<.001	3	>.001	------	.001	<.001	<.001	(3)
126	.3	.01	.001	3	>.001	0.01	.001	.003	<.001	(3)
131B	.3	.01	.001	3	>.001	.01	.001	<.001	<.001	(3)
56AMK-1	.003	.03	------	3	.01	.01	.003	.001	.001	(3)
159	.01	.03	------	3	.01	------	.003	<.001	.001	(3)
168	.01	.03	------	3	.01	------	.001	.001	<.001	(3)
219	.01	.03	------	3	.03	.03	.003	.01	------	(3)
225	------	.03	------	3	.003	------	.003	------	------	(3)
233	.01	.03	------	3	.03	.03	.001	.003	------	(3)
234	.003	.03	------	3	.01	.01	.003	<.001	------	(3)

See footnotes at end of table.

TABLE 13.—*Semiquantitative spectrographic analyses and equivalent and chemical uranium analyses of the plutonic rocks*—Continued

Sample	Sn	Sr	Th	Ti	U	V	Y	Yb	Zn	Zr
57AMK-110	--------	0.03	--------	0.1	--------	0.01	--------	--------	--------	0.01
66B	--------	.1	--------	.1	--------	.03	0.001	<0.001	--------	.001
25	--------	.1	--------	.3	--------	.01	.003	<.001	--------	.03
141	--------	.03	--------	.3	--------	.01	--------	--------	--------	.003
56AMK-143A	--------	.03	--------	.3	--------	.01	.001	<.001	--------	.003
132	--------	.03	--------	.3	--------	.01	.003	<.001	--------	.01
57AMK-17	--------	.1	--------	.3	--------	.03	.003	<.001	0.01	.01
19	--------	.3	--------	.3	--------	.01	.001	<.001	.01	.003
20	--------	.3	--------	.3	--------	.01	.003	<.001	--------	.01
62A	--------	.1	--------	.3	--------	.01	.003	<.001	--------	.03
21	--------	.1	--------	.3	--------	.01	.003	<.001	--------	.01
34	--------	.1	--------	.1	--------	.01	.001	<.001	--------	.01
80	--------	.01	--------	.03	--------	--------	.003	<.001	--------	.01
56AMK-134	--------	.01	--------	1	--------	--------	.003	<.001	--------	.01
138	--------	.01	--------	1	--------	--------	.001	<.001	--------	.01
88	--------	.01	--------	.1	--------	--------	.01	<.001	--------	.01
116	--------	.01	--------	1	--------	--------	.001	<.001	--------	.01
124	--------	.01	--------	.1	--------	--------	.003	<.001	--------	.01
140	--------	.01	--------	1	--------	--------	.001	<.001	--------	.01
151	--------	.01	--------	.1	--------	--------	.003	<.001	--------	.01
57AMK-56	--------	.03	--------	.1	--------	<.001	.003	<.001	--------	.01
62	--------	.03	--------	.1	--------	<.001	.003	<.001	--------	.01
126	--------	.1	--------	.1	--------	.003	.003	<.001	--------	.03
131B	--------	.1	--------	.1	--------	.003	.003	<.001	--------	.01
56AMK-1	0.01	<.001	0.003	.1	0.003	--------	.003	.003	--------	.3
159	.003	.001	.003	.1	.003	--------	.01	.003	--------	.3
168	.003	<.001	.003	.1	.001	--------	.01	.001	.01	.03
219	.003	.003	.001	.1	.003	--------	.03	.003	.01	.1
225	--------	--------	--------	.03	.003	--------	.003	.001	--------	.1
233	.003	.01	.1	.1	.03	--------	.1	.01	.003	.03
234	--------	.001	.001	.1	.01	--------	.03	.003	--------	.1

[1] Chemical uranium analyses by Joseph Budinsky, Esma Campbell, Irving May, and Roosevelt Moore, U.S. Geol. Survey.

[2] Radiometric analyses by B. A. McCall, U.S. Geol. Survey.

[3] Much greater than 10.

ALKALI METALS

Lithium, the only alkali metal considered here, was detected in minor amounts in only one sample, a peralkaline granite, and its mode of occurrence is not known.

ALKALINE EARTH METALS

The alkaline earth metals that are considered in this report are beryllium, strontium, and barium, lithophile elements that are characteristically distributed in silicate minerals in igneous rocks.

BERYLLIUM

Beryllium is sparingly represented in all of the rocks except the pyroxenite, gabbro, and the albitized diorite. The maximum amount of beryllium that was detected, 0.001 percent, was found in one of the albitized quartz monzonites and in three of the peralkaline granites. These values are in fair accord with data on the distribution of beryllium in igneous rocks cited by Rankama and Sahama (1950, p. 444) and by Goldschmidt (1954, p. 207), and indicate a minor enrichment of beryllium in late-stage magmatic residuum.

No beryllium minerals were found in the rocks. Probably minor amounts of beryllium entered into the lattices of some of the aluminum- or silicon-bearing minerals, such as feldspars, amphiboles, or pyroxenes.

STRONTIUM

Strontium was detected in all of the rocks. It is least abundant in the peralkaline granite and attains its maximum abundance, 0.3 percent, in an albitized quartz diorite and a granodiorite. It is fairly abundant in most of the other rocks that were tested. The distribution of strontium is in accord with data in Goldschmidt (1954, p. 245) and in Rankama and Sahama (1950, p. 476) indicating that strontium in plutonic rocks is more abundant in syenite and diorite, and especially abundant in nepheline syenite.

In most of the plutonic rocks, strontium is believed to have substituted for calcium in the anorthite molecule. This is particularly true for the quartz diorite, granodiorite, and the quartz monzonite. In the syenite strontium apparently substituted for potassium in K-feldspar.

BARIUM

The barium content ranges from 0.001 percent in the peralkaline granite to 1 percent in the syenite. It is fairly high in the granodiorite, quartz monzonite, and gneissic quartz monzonite, but it forms 0.03 percent or less of the other rocks.

The distribution of barium correlates with the distribution of K-feldspar for most of the rocks, and it can be accounted for by the capture of barium by potassium-bearing minerals, chiefly K-feldspar. This is especially true for the syenite. However, the late peralkaline granite, despite its plentiful K-feldspar, contains only minor amounts of barium. This paucity can be reconciled with the belief that most of the barium had entered the earlier formed K-feldspar crystals, and that the late residual liquid, which formed the peralkaline granite, was virtually impoverished in barium. In the mafic rocks probably some barium has substituted for potassium in biotite.

LIGHT ELEMENTS OF GROUP III

The light elements of group III that are discussed are boron and scandium.

BORON

Boron was detected in the pyroxenite, gabbro, quartz diorite, albitized quartz diorite, and granodiorite, in quantities as much as 0.003 percent. No minerals in which boron is an essential constituent were found in the plutonic rocks, and the mode of occurrence of boron in these rocks is not known. It may have locally replaced silicon in silicon-oxygen tetrahedra.

SCANDIUM

Scandium was found in minor amounts in representatives of all of the rocks ranging from <0.001 percent in the syenite, gneissic quartz monzonite, and some peralkaline granites to 0.01 percent in two of the albitized dioritic rocks. These results indicate that scandium is dispersed in small amounts throughout the intrusive rocks According to Rankama and Sahama (1950, p. 513) scandium can be captured by magnesium and ferrous iron in mineral structures, but scandium is unable to replace magnesium in all mineral structures. The scandium probably occurs mainly in mafic minerals, chiefly biotite and hornblende. Goldschmidt's work, cited in Rankama and Sahama (1950, p. 516) shows that ultramafic rocks and gabbro are slightly enriched in scandium, but this tendency is not shown in the rocks of the Bokan Mountain area.

RARE-EARTH ELEMENTS

The rare-earth elements discussed herein include three in the cerium subgroup and four in the yttrium subgroup. The abnormal amount of rare earths in some of the late-stage rocks, particularly the peralkaline granite and its associated dikes, is one of the most interesting petrologic and geochemical features of the rocks.

The rare-earth group is closely similar chemically, a fact that is attributed to the additional electrons in successive rare-earth elements being used for completion of the N level inside the levels of valency electrons (Goldschmidt, 1954, p. 312). The rare earths tend to concentrate in the late phases of magmatic differentiation. Correlating some igneous rocks has been aided by the systematic studies of their rare earth assemblages (Landergren, 1948; Sahama, 1945).

CERIUM SUBGROUP RARE EARTHS

Three elements in the cerium subgroup, cerium, lanthanum, and neodymium, were detected in the plutonic rocks. Cerium was found in all except one of the peralkaline granite samples in quantities as much as 0.3 percent. Lesser amounts of cerium were detected in the syenite, two of the granodiorites, and in one quartzdiorite. Lanthanum was found in all of the peralkaline granite samples except one in amounts as much as 0.03 percent. Lesser amounts of lanthanum were detected in the syenite, gneissic quartz monzonite, granodiorite, and quartz diorite. Cerium and lanthanum tend to occur in near-equal quantities in a spceific sample and show a marked enrichment in rocks late in a magmatic series, such as the peralkaline granite.

Neodymium was detected in four of the peralkaline granite samples in amounts as much as 0.03 percent and in the syenite.

The cerium subgroup rare earths are apparently closely associated with each other in the minerals that they form. These elements probably occur in minor amounts as exotic constituents in many minerals in the plutonic rocks, particularly in the peralkaline granite. Acmite always contains notable amounts of rare earths (Dana and Ford, 1932, p. 562). Cerium and lanthanum can substitute for the essential yttrium in xenotime (Palache and others, 1951, p. 690).

Cerium subgroup elements can probably also enter into the lattices of zircon and uranothorite. They may constitute minor amounts of apatite (Goldschmidt, 1954, p. 315), but apparently this is not so in the Bokan Mountain area for no cerium subgroup rare earths were found in the rocks that are richest in apatite, the mafic and the ultramafic rocks. Some of the fluorite and sphene may also carry minor quantities of these rare earths. Cerium subgroup rare earths are constituents of monazite and allanite. Monazite occurs both in the albitized and the unalbitized quartz monzonite and granodiorite, while allantite was questionably identified in the albitized quartz monzonite. The fact that no cerium subgroup elements were found in the quartz monzonites is attributed to the vagaries of sampling.

YTTRIUM SUBGROUP RARE EARTHS

Four of the ten yttrium subgroup rare earth elements, yttrium, ytterbium, dysprosium, and erbium, were found in the plutonic rocks. Yttrium and ytterbium were found in all of the rocks except the pyroxenite. Both of these elements show a roughly progressive increase in abundance from the older more mafic rocks to the younger more silicic rocks and attain their maximum concentration in the peralkaline granite. The ratio of yttrium to ytterbium is generally between 3 and 10.

Probably the distribution of the yttrium subgroup elements in discrete minerals correlates largely with the distribution of xenotime and zircon, both of which are most abundant in the peralkaline granite. Yttrium, besides being an essential constituent of xenotime, can be substituted for by erbium in considerable amounts in this mineral (Palache and others, 1951, p. 690). The yttrium subgroup elements are believed also to be found in subordinate amounts in most of the minerals considered as likely carriers of cerium subgroup elements that are described in the preceding section.

FIRST TRANSITION ELEMENTS

All of the first transition elements except iron are considered in this report. These elements are widespread throughout the plutonic rocks, but, except for titanium and manganese, they occur in very minor amounts.

TITANIUM

Titanium was found in all of the plutonic rocks. Its maximum abundance is 1 percent in the albitized quartz monzonite and granodiorite. It is generally distributed in the other rocks in amounts between 0.1 and 0.3 percent.

The distribution of titanium is largely accounted for by minerals in which titanium is an essential constituent. These include: ilmenite, which undoubtedly forms a part of the undetermined opaque minerals that are associated with all of the rocks; sphene, which occurs in most of the rocks and is particularly common in the granodiorite and quartz monzonite and their albitized phases; leucoxene, which occurs in several of the rocks and is in greatest concentrations in the albitized quartz monzonites and granodiorites; and rutile(?), which occurs in minor amounts in the peralkaline granite.

The riebeckite from the peralkaline granite that was chemically analyzed (table 5) contained 0.68 percent TiO_2. In this mineral the titanium apparently has a valence of plus three and partly substitutes for aluminum or ferric iron. Some of the other mafic minerals may also contain small amounts of titanium incorporated in their crystal lattices in an analogous manner.

VANADIUM

Vanadium was detected in all of the plutonic rocks except the albitized quartz monzonites and granodiorites and the peralkaline granite. It is most abundant in some of the dioritic rocks. This distribution is in accord with the tenet that the highest vanadium content in igneous rocks is found in those rocks associated with the initial steps of the main stages of crystallization.

Probably most of the vanadium is closely associated with iron and is in such minerals as magnetite and ilmenite. Possibly pentavalent vanadium has replaced small amounts of phosphorous in some of the apatite.

CHROMIUM

Chromium occurs in minor amounts in all of the plutonic rocks except the gabbro and is only notably concentrated in the pyroxenite in which it forms 0.1 percent. No specific chromium minerals were identified, but subordinate amounts of chromite probably occur in the pyroxenite. Most chromium is believed to be closely associated with ferric iron and may form small parts of some oxides that contain ferric iron, or trace amounts of chromium may be associated with some of the iron in mafic silicates.

MANGANESE

Manganese appears to be dispersed in all the plutonic rocks. Its highest concentration, 0.1 percent, is in the dioritic rocks. This distribution is in accord with Goldschmidt's (1954, p. 628) belief that the crystallization of manganese in magmatic rocks is dominated by two opposing trends: the general decrease in the total amounts of the first transition elements toward the late members of any series of magmatic evolution, and the increase in relative amounts of manganese with respect to the other first transition elements in residual magmas. Accordingly most manganese should be concentrated in the early intermediate magmatic products, such as the dioritic rocks, as in the Bokan Mountain area.

No minerals in which manganese is an essential element were found in the plutonic rocks. The manganese is probably in the manganous state and closely associated with ferrous iron, which being much more abundant, tends to obscure it. Probably most manganese occurs in the oxides and mafic silicates that contain ferrous iron.

COBALT

Cobalt is present in very minor amounts in all of the plutonic rocks except the albitized quartz monzonite, the gneissic quartz monzonite, and the peralkaline granite. Its largest concentration, 0.01 percent, was in a sample of albitized quartz diorite.

The cobalt probably is in part concealed in the structures of mafic silicates, where it substitutes for magnesium and in part is associated with pyrite which is fairly abundant in many of the rocks.

NICKEL

Nickel was found in all of the plutonic rocks except the albitized quartz monzonite and granodiorite. As expected, its highest concentration is in the pyroxenite, which contains 0.03 percent nickel. Nickel is next most abundant in some of the peralkaline granites and in a quartz diorite.

No nickel minerals were found during the present investigation. The relative enrichment of nickel in the pyroxenite is attributable to nickel being incorporated mainly in the lattices of some of the ferro magnesium minerals formed earlier. Small amounts of nickel may also be associated with pyrite and in mafic minerals in some of the younger rocks.

SECOND TRANSITION ELEMENTS

The second transition elements discussed are zirconium, niobium, and molybdenum. These elements are characteristically most abundant in the late-stage products of magmatic differentiation.

ZIRCONIUM

Zirconium was found in all of the samples, ranging from 0.001 percent in the gabbro to 0.3 percent in some peralkaline granite. Its tendency to concentrate in late-stage magmatic phases is illustrated by its relative abundance in the peralkaline granite.

The zirconium is probably entirely contained in zircon, and its abundance correlates well with that of zircon, which is fairly common in the late-stage rocks. Zircon was not found in the pyroxenite, gabbro, or in the albitized dioritic rocks, but more extensive thin section studies would probably reveal small amounts of it in these rocks.

NIOBIUM

Niobium is typically an element of the late crystallates of magmatic differentiation, and it was found in all samples of the peralkaline granite in amounts as much as 0.03 percent. Lesser quantities of niobium were detected in the syenite, gneissic quartz monzonite, granodiorite, and in one sample of albitized quartz diorite.

No niobium-bearing minerals were identified in the plutonic rocks. According to Rankama and Sahama (1950, p. 607) niobium is a satellite of both titanium and zirconium and small amounts of niobium can occur in such minerals as sphene and zircon. Such occurrences would aid in rationalizing the distribution of niobium in the plutonic rocks.

MOLYBDENUM

Molybdenum was found in minor amounts in all the plutonic rocks except the albitized diorite, the albitized quartz monzonite and granodiorite, and the peralkaline granite. Its greatest concentration, 0.001 percent, is in the syenite and in one albitized quartz diorite. The mode of occurrence of the molybdenum is not known as no molybdenum-bearing minerals were found.

SUBGROUPS I AND II

Only one element from each of these subgroups was investigated, copper from subgroup I and zinc from subgroup II. These predominantly chalcophile elements are not particularly abundant in the Bokan Mountain area plutonic rocks.

COPPER

Small quantities of copper were found in all of the rocks. Its largest concentration, 0.01 percent, was in the albitized diorite, and in one sample each of the albitized quartz diorite and the peralkaline granite. Although chalcopyrite was not found, it is probable that minute quantities of this mineral are associated with some of the pyrite, and that they contain most of the copper in the plutonic rocks. It is also conceivable that small amounts of copper may have replaced ferrous iron in some of the mafic minerals.

ZINC

Zinc was detected in three samples of the peralkaline granite and in two of albitized quartz diorite in amounts as much as 0.01 percent. The occurrence of the zinc is not readily explained. Presumably it is present chiefly in ferromagnesium minerals, where it can replace either ferrous iron or magnesium. But why it should be found in some rocks and be absent in others that are just as rich or richer in mafic minerals is not known.

SUBGROUPS III AND IV

Three of the six elements in subgroups III and IV are discussed in this report, gallium in subgroup III and tin and lead in subgroup IV.

GALLIUM

Gallium was detected in all of the rocks ranging from 0.001 percent in the pyroxenite and some of the albitized rocks to 0.01 percent in some of the peralkaline granite. According to Rankama and Sahama (1950, p. 720), gallium in the upper lithosphere is strongly oxyphile, and it largely occurs in silicate minerals, an occurrence governed by the diadoche between gallium and aluminum. The gallium in rocks of the Bokan Mountain area is believed to have replaced aluminum, particularly in feldspars, but to lesser extent in amphiboles and pyroxenes.

TIN

Tin was found in five of the analyzed samples of peralkaline granite but in no other plutonic rocks. This distribution of tin is in accordance with tin's preference for the late crystallates of magmatic differentiation. The abundance of tin in the peralkaline granite roughly correlates with that of fluorite, and some tin may be incorporated in the fluorite. Other postulated hosts for tin (Rankama and Sahama, 1950, p. 732) are silicate minerals that contain ferrous iron or calcium. In such minerals the stannic ion may replace the ferrous ion and the stannous ion substitutes for calcium.

LEAD

Minor amounts of lead were detected in most of the plutonic rocks. The largest amount, 0.01 percent, was in a sample of peralkaline granite. The lead roughly increases in quantity from the older more mafic rocks to the younger more leucocratic rocks, a distribution that is in accord with lead's known preference for the late-stage rocks of a magmatic series. No lead minerals were found in the rocks, although galena is a minor constituent of some hydrothermal deposits in the area. The lead probably has partially replaced calcium in such minerals as apatite and fluorite, and partially replaced potassium in K-feldspar. Some of the lead is probably radiogenic.

RADIOACTIVE ELEMENTS

Two radioactive elements, thorium and uranium, are discussed. The differences between the apparent uranium and thorium contents in most of the plutonic rocks is partly traceable to the analytical methods used. Uranium was analyzed for by sensitive chemical methods, whereas much less sensitive spectrographic methods were used in the analysis for thorium. Contrary to the analytical results, thorium is from two to four times more abundant than uranium in most granitic rocks (Larsen and Phair, 1955, p. 77). Both thorium and uranium apparently became slightly concentrated in the late-stage parent magma of the peralkaline granite.

THORIUM

Thorium was found only in the peralkaline granite in amounts as much as 0.1 percent. Subordinate amounts of thorium undoubtedly occur in the other rocks, but were not detected. The discrepancies in many of their equivalent and chemical analyses for uranium indicate that such rocks contain thorium.

Within the plutonic rocks, minerals that contain thorium as an essential constituent are uranothorite and uranoan thorianite(?). Thorium may also occur in monazite, allanite, zircon, sphene, apatite, epidote, and xenotime.

URANIUM

Uranium was detected by chemical analyses in all of the rocks, ranging in amounts from <0.001–0.020 percent. The highest concentrations are in the peralkaline granite, which along with the albitized quartz monzonite and granodiorite are slightly enriched in uranium.

The uranium in igneous rocks is mainly in the quadrivalent state and is characteristically concentrated in the late-stage rocks. In the plutonic rocks, uranium is found chiefly in such minerals as uranothorite and uranoan thorianite(?). Identification of the primary uranium and thorium minerals is rather difficult, for most of them are in the metamict or partly metamict state. Small amounts of uranium probably occur in sphene, apatite, monazite, allanite, xenotime, and epidote. The distribution of uranium in many of these minerals is analogous to that of thorium.

In some occurrences uranium partly replaces thorium. This type of replacement has taken place in such minerals as uranothorite and uranoan thorianite. Palache and others (1946, p. 612) report that a complete isomorphous series between ThO_2 and UO_2 has been produced artificially, but that its natural counterpart has not been found. Uranium is also known to substitute for calcium, and yttrium subgroup rare earth elements (Goldschmidt, 1954, p. 562). Pleochroic halos around some of the minor accessory minerals included in biotite, particularly some zircon, xenotime, and monazite, are further evidence that they contain uranium or thorium.

MINOR ELEMENTS IN THE HYPABYSSAL ROCKS

The hypabyssal rocks that were analyzed include one aplite that is related to the peralkaline granite, three pegmatites that are related to the peralkaline granite, two pegmatites that are related to the quartz monzonite or granodiorite, and two dacites (table 14).

The aplites and pegmatites that are related to the peralkaline granite contain the most varied and abundant assemblage of minor elements of any rocks in the area. They contain noteworthy amounts of many rare earth elements, niobium, uranium, thorium, and zirconium. Their minor element content is similar to that of the peralkaline granite (table 13) but it is larger and more diversified. It is also similar to many of the uranium-thorium deposits of the area (tables 7, 8, and 9), and many of the aplites and pegmatites that are related to the peralkaline granite constitute potential ores. Most of the hypabyssal rocks that are related to the peralkaline granite are altered and some minor elements probably were introduced by hydrothermal solutions.

The pegmatites that are affiliated with the quartz monzonite or granodiorite lack the suite of minor elements that is typical of the peralkaline granite and its related rocks.

TABLE 14.—*Semiquantitative spectrographic analyses and equivalent uranium analyses of the hypabyssal rocks*

[Semiquantitative spectrographic analyses by Joseph Haffty, C. L. Waring, and H. W. Worthing, U.S Geol. Survey. Values for the semiquantitative spectrographic analyses are reported in percent to the nearest number in the series, much greater than 10, 10, 3, 1, 0.3, 0.1, 0.03, 0.01, 0.003, 0.001. Standard sensitivities for the elements sought in the semiquantitative spectrographic analyses are shown in table 11. Dashes indicate not detected]

Sample	Name	Percent--		Ag	Al	As	B	Ba	Be	Ca
		cU[1]	eU[2]							
57AMK-15	Aplite	0.025	0.040	--------	10	------	0.003	0.01	0.001	0.3
56AMK-158	Pegmatite	.042	.046	<0.001	3	0.01	.003	.03	.003	.03
217	Zircon-rich pegmatite	.06	.064	.001	.3	------	-------	.01	<.001	.01
227	Pegmatite	.007	.017	<.001	3	------	-------	.01	<.001	.01
57AMK-66A	Pegmatite	<.001	.005	--------	10	------	-------	.03	-------	.1
104	Pegmatite	<.001	.006	--------	10	------	-------	.1	-------	.3
56AMK-79	Dacite	.007	.004	--------	3	------	-------	.01	-------	.3
143B	Dacite	.002	.002	--------	3	------	-------	.03	-------	3

See footnotes at end of table.

TABLE 14.—*Semiquantitative spectrographic analyses and equivalent uranium analyses of the hypabyssal rocks*—Continued

Sample	Ce	Co	Cr	Cu	Dy	Er	Eu	Fe	Ga	Gd	Hf	Ho	K
57AMK-15	1	------	0.001	<0.001	0.03	0.01	0.01	3	0.003	0.1	0.003	0.003	0.3
56AMK-158	1	------	.003	.01	.1	.1	------	10	.001	.03	.03	.003	3
217	----	0.003	.001	.001	.1	.1	------	10	------	------	.1	.01	----
227	.1	------	.001	.001	.03	.03	------	3	.001	------	.03	------	1
57AMK-66A	----	------	<.001	.001	------	------	------	1	.003	------	------	------	10
104	----	------	<.001	.001	------	------	------	1	.003	------	------	------	10
56AMK-79	----	------	.03	.001	------	------	------	10	.003	------	------	------	----
143B	----	.003	.01	.01	------	------	------	3	.001	------	------	------	1

Sample	La	Lu	Mg	Mn	Mo	Na	Nb	Nd	Ni	Pb	Pr	Sc
57AMK-15	1	0.001	1	0.1	0.001	3	0.1	1	0.003	0.003	0.1	0.01
56AMK-158	0.3	------	.003	.03	------	.3	.1	.1	------	.01	.03	------
217	----	.01	.003	.03	------	1	.01	------	------	.003	------	------
227	----	.003	.003	.03	------	1	.01	.03	------	<.001	------	------
57AMK-66A	----	------	.03	.01	------	3	------	------	<.001	.003	------	------
104	----	------	.1	.01	<.001	1	------	------	.001	.003	------	<.001
56AMK-79	----	------	3	.03	------	3	------	------	.01	------	------	------
143B	----	------	3	.1	------	1	------	------	.003	------	------	.003

Sample	Si	Sm	Sn	Sr	Tb	Th	Ti	Tm	V	Y	Yb	Zr
57AMK-15	(3)	0.1	0.003	0.1	0.01	0.1	0.1	0.01	0.01	0.3	0.03	1
56AMK-158	(3)	.03	.03	.01	----	.1	1	------	------	.3	.03	3
217	(3)	------	.003	------	----	.1	.1	------	------	.3	.1	(3)
227	(3)	------	.01	.001	----	------	.1	------	------	.1	.03	3
57AMK-66A	(3)	------	------	.01	----	------	.01	------	<.001	.001	<.001	.003
104	(3)	------	------	.03	----	------	.03	------	<.001	------	------	.003
56AMK-79	(3)	------	------	.01	----	------	1	------	.01	.001	<.001	.003
143B	(3)	------	------	.03	----	------	.3	------	.01	------	------	.001

[1] Chemical uranium analyses by Joseph Budinsky and Roosevelt Moore, U.S. Geol. Survey.
[2] Radiometric analyses by B. A. McCall, U.S. Geol. Survey.
[3] Much greater than 10.

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