GEOLOGICAL SURVEY RESEARCH 1971

Chapter D

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GEOLOGIC STUDIES

GEOLOGICAL SURVEY RESEARCH 1971

This collection of 39 short papers is the third published chapter of "Geological Survey Research 1971." The papers report on scientific and economic results of current work by members of the Geologic and Water Resources Divisions of the U.S. Geological Survey.

Chapter A, to be published later in the year, will present a summary of significant results of work done in fiscal year 1971, together with lists of investigations in progress, reports published, cooperating agencies, and Geological Survey offices.

"Geological Survey Research 1971" is the twelfth volume of the annual series Geological Survey Research. The eleven volumes already published are listed below, with their series designations.

Geological Survey Research	*Prof. Paper*
1960	400
1961	424
1962	450
1963	475
1964	501
1965	525
1966	550
1967	575
1968	600
1969	650
1970	700

GEOLOGY AND GEOCHEMISTRY OF THE SINUK RIVER BARITE DEPOSIT, SEWARD PENINSULA, ALASKA

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Abstract.—Barite, fluorite, galena, sphalerite, boulangerite, and associated silver and gold were introduced into thrust sheets of marble and schist of the Nome Group (Precambrian age) in the Sinuk River barite deposit along the Teller Highway about 20 miles north of Nome on the Seward Peninsula, Alaska. Most of the introduced minerals were emplaced pervasively, followed by some later shearing and recrystallization which occurred at a temperature of about 250°C, as indicated by study of fluid inclusions in the fluorite. Fissure fillings consisting principally of calcite and aragonite with some sulfide minerals and associated gold and silver possibly indicate a second epoch of mineralization in the area. The vertical and lateral extent of the mineralization is unknown, although gossans with base metals are known in the surrounding region. Mineralization might have taken place in shear zones between thrust sheets or might have penetrated favorable host rocks in either the overriding or underlying sheet or both. Further exploration seems warranted.

Barite, fluorite, goethite, galena, sphalerite, boulangerite, and associated silver and gold occur in marble and schist in the Sinuk River barite deposit that lies adjacent to the Teller Highway about 20 miles north of Nome on the Seward Peninsula, Alaska (fig. 1). The deposit, also known as the quarry prospect (Herreid, 1966, p. 3), lies on the divide between the Cripple River and Washington Creek, a tributary of the Sinuk River, in the NW¼ sec. 19 (and adjacent sections), T. 9 S., R. 35 W., in the Nome C-2 quadrangle. New observations on the stratigraphic, structural, and mineralogical features of the barite deposit suggest that a large area is worthy of exploration for mineral deposits of commercial value.

In earlier times, the interest of prospectors and geologists has been drawn to the Sinuk River area by gossans. Eakin (1915) first described the gossans and after spending only a day in the area had the general impression (p. 362), "that there had been strong mineralization at certain localities, and that the mineralizing agencies had affected a considerable area." The gossans were examined by A. B. Shallit (unpub. data) in 1942 for the Alaska Territorial Department of Mines and again by Mulligan (1965) and rejected as sources of iron ore. Some geologic and geochemical work was done in the area

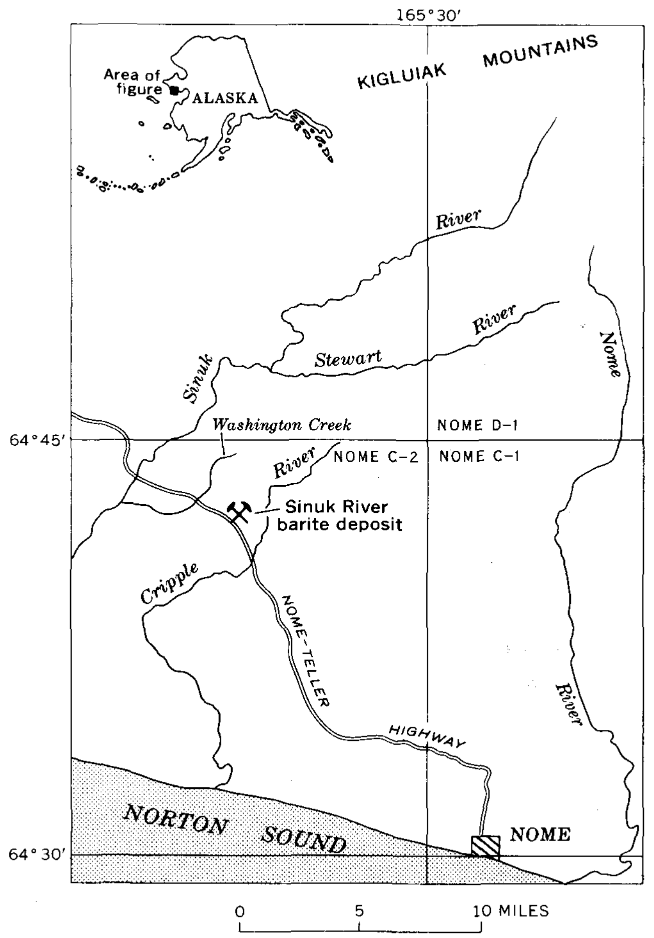

Figure 1.—Index map of the Nome area, Seward Peninsula, showing the location of the Sinuk River barite deposit.

by Herreid (1966, p. 3, figs. 1, 3), who reported a strong geochemical anomaly for lead and zinc in the soil of an area 2,000 by 6,000 feet. This area includes a large borrow pit from which road metal was taken for construction of the Teller Highway. The pit became known as the quarry prospect. Recently Mr. Charles Volkheimer and associates, of Nome, found barite in the pit and staked the quarry site and environs as the Sinuk River barite claims.

In August 1970, Brobst spent 2 days examining and sampling the Sinuk River barite deposit after an introduction to the geology of the area by Sainsbury, who has supplied much information on the local stratigraphy and geology of the Seward Peninsula. Studies of the fluid inclusions were contributed by Pinckney. Additional studies of the samples included petrographic examination of thin and polished sections, mineral identifications by X-ray diffraction, spectrographic analyses of rocks and minerals, and fire assays for precious metals. The authors acknowledge the assistance of L. A. Bradley for the spectrographic analyses, J. B. McHugh for the instrumental determinations of mercury, W. D. Goss, A. W. Haubert, J. A. Thomas, and L. B. Riley for the fire assays, J. D. Tucker for the X-ray diffractograms, and Irving Friedman and K. G. Hardcastle for the determination of the carbon dioxide-to-water ratio in the fluid inclusions. The authors also thank Mr. Charles Volkheimer and associates for permission to publish the results of this study.

BARITE-FLUORITE DEPOSIT

The deposit is exposed in a stripped area about 225 by 1,000 feet, the long dimension of which trends about N. 10° W. up a gently sloping hill. The cut exposes a sequence of folded interlayered marble and chloritic schist in three benches referred to as the upper, middle, and lower benches. The upper bench is composed mostly of marble, but contains some schist. A shaft and short unroofed crosscut lie in the northwest corner of the middle bench. This bench is composed mostly of schist and some marble. The lower bench occupies the southern third of the cut and also is composed mostly of schist. A geologic map of the cut as it appeared in 1965 was included in a report by Herreid (1966, fig. 3), but the map showed only parts of what are now the upper and middle benches.

A detailed stratigraphic sequence of marble and schist was not worked out, but marble seems to be more abundant in the upper than in the lower part of the sequence in the cut. The rocks are assigned by Sainsbury to the Nome Group, which comprises a thick sequence of interbedded schistose marble and epidote-chlorite-albite-actinolite schists of Precambrian age. Similar rocks crop out over large areas of the Seward Peninsula; they are well described by Moffit (1913), Smith (1910), and Sainsbury, Coleman, and Kachadoorian (1970).

The marble and schist have been deformed, thermally altered and pervasively mineralized to various degrees. The compositional layers and foliation have various attitudes in the exposures, but a general southeasterly dip prevails at the cut. A well-developed lineation trends slightly east of south and generally plunges 15° to 30° SE. Steeply dipping veins only a few inches wide, consisting mostly of colloform calcite and aragonite, trend west and transect the earlier structural features. The ore deposits occur principally along the foliation planes of the host rocks, but some veins and veinlets crosscut both the marble and the schist.

At several places in the cut, the marble was replaced by masses of pale-yellowish-orange dolomite. A sample of this rock consists of cloudy grains of dolomite about 0.01 mm across. The rock is cut by thin veinlets of calcite and sulfide. The sulfide minerals apparently account for the lead, zinc, antimony, and silver shown in the spectrographic analysis (table 1, sample 17).

Some of the dolomite has been brecciated to angular fragments 3 mm to 3 cm across and cemented by fine-grained white quartz that is free of inclusions. Some sericite lies in the interstices of both the quartz and the carbonate. X-ray diffraction analysis indicated that some calcite and fluorite also occur in the breccia. The brecciated dolomite also contains some sulfides which probably account for the lead, zinc, and silver shown in the spectrographic analysis (table 1, sample 22).

COUNTRY ROCKS

The unmineralized marble exposed at the deposit is gray to bluish white and is composed of more than 95 percent calcite, commonly twinned, with a grain size of 0.1 to 1 mm. The marble is schistose, its foliation accentuated by thin layers of shiny flakes of sericite interstitial to the calcite. Round to subangular grains of quartz 0.02 to 0.2 mm in diameter are scattered through the rock. Spectrographic analyses of two fresh samples of this marble from the upper and lower benches are shown in table 1 (samples 7 and 18). These analyses indicate the low initial content of barium.

Some of the marble has been altered by bleaching and dolomitization. Bleaching produced streaks and patches of white marble within the unaltered gray marble. Some of the bleached rock is stained by iron oxides.

The least altered schists are silvery to dark greenish gray and consist of various proportions of quartz, muscovite (including sericite), and chlorite associated with smaller amounts of albite, epidote, hornblende, garnet, magnetite-ilmenite, and sulfide minerals. The streaks of micaceous minerals are bent and broken and separated by streaks of quartz in grains 0.1 to 0.2 mm across. Some muscovite and chlorite are included in the quartz, some sericite occurs interstitially to the quartz, and some grains and patches of calcite are associated with quartz. Some schist contains small grains of high-calcium garnet (andradite) which is pale red and greatly fractured. Elongate streaks of opaque ilmenite-magnetite and sulfide minerals occur with the muscovite. Spectrographic analyses of two samples of this type of schist from the west side of the middle bench are shown in table 1 (samples 20 and 21). The suite and amount of the trace elements, especially the zinc and antimony, certainly suggest that even the freshest appearing schist has been hydrothermally altered.

Because the schist has been altered pervasively, the marble also probably was altered similarly. If so, the streaks and patches of either bleached or dolomitized rock mentioned above indicate places where the marble was more intensely altered.

INTRODUCED MINERALS

The introduced minerals occur chiefly as streaks and pods in the pervasively altered schist and marble and to a much lesser extent as thin veins which trend west across the exposures. The streaks and pods are a few inches to several feet thick and as much as several tens of feet long. They contain various amounts and combinations of barite, fluorite, sulfides of lead, zinc, antimony, and iron, and precious metals, along with their weathering products and a gangue of calcite, dolomite, and quartz. The streaks and pods generally follow the foliation of the host rocks and the contacts of the various layers of marble and schist.

White barite occurs mostly in marble on the upper bench and is especially abundant in a bulldozer cut adjacent to the northwest side of the main cut. The barite (sample 3) from the bulldozer cut is sugary grained and has a lineation induced by shear. In thin section the grains of barite are 0.5 to 1.5 mm across, and many are twinned. The only accessory minerals observed are scattered round grains of quartz and pyrite, the latter surrounded by thin rims of iron oxide. A similar-looking specimen of barite (sample 25) from the north end of the upper bench contains a little calcite. The texture of both samples is sutured, and relict grain boundaries are indicative of at least a partial recrystallization of the barite. Spectrographic analyses of barite samples 3 and 25 (table 1) indicate a good-quality barite. The strontium values are not especially unusual, because barium and strontium freely substitute to several percent in their respective sulfates.

Barite also occurs with other minerals in some of the pods; for example, with fluorite and quartz in the crest of a small fold in marble on the upper bench. In a sample from this locality, grains of barite and fluorite, 0.1 to 0.2 mm across, are scattered in finer grained quartz. Some small amounts of sericite lie in the interstices of the aforementioned minerals. Some round grains of pyrite only 0.04 mm in diameter are scattered through the sample. The spectrographic analysis (table 1, sample 8) suggests that most of the material analyzed is barite.

The fluorite occurs in clots and streaks from several inches to several feet across. Most of the fluorite is white or light green and purple, but some is colorless. Most of the fluorite examined under the microscope has been sheared and at least partly recrystallized; relict traces of former grain boundaries are easily visible. Some fractures as wide as 0.1 mm are filled by quartz or calcite. In some thin sections, hair fractures and cleavage planes are "corroded" by calcite, and the fluorite apparently has been thoroughly penetrated by later solutions. The fluorite regarded as typical of this deposit is nearly pure. Spectrographic analyses of seven samples of fluorite shown in table 1 (samples 4, 5, 6, 9, 10, 11, and 19) indicate very little barium or other elements.

The sulfides galena (PbS), sphalerite (ZnS), and boulangerite ($Pb_5Sb_4S_{11}$) have been identified in polished sections and by X-ray diffraction. They occur as scattered grains or aggregates in the clots and streaks with other introduced minerals and as finely disseminated grains in the calcite and aragonite of the late west-trending veins.

Some of the sulfide minerals are sheared and some are not. Textural relations suggest that at least some of the sulfide minerals were introduced later than the fluorite and barite.

A body of quartz-rich rock on the east side of the middle bench has discontinuous thin streaks of sheared galena. The quartz matrix has been partly recrystallized, and some of the relict boundaries have been preserved. A spectrographic analysis of this rock (table 1, sample 15) also indicates the presence of anomalous silver and antimony.

Sheared yellow-orange fluorite-calcite-quartz rock with goethite at a marble-schist contact on the east side of the middle bench contains streaks or veins of unsheared quartz, galena, and boulangerite; this veining suggests that the latter minerals perhaps are younger than the enclosing sheared rock. Spectrographic analyses of this material are shown in table 1. Sample 14A is the sheared fluorite-rich rock. Sample 14B, the unsheared quartz-sulfide vein, contains 2,000 ppm arsenic, but no specific arsenic minerals were identified. Sample 14 is a composite of the sheared and unsheared material. The traces of tin, molybdenum, and rare earths found in these samples are similar to those known in many altered rocks on the Seward Peninsula.

Herreid (1966) reported some silver and gold in the rocks of this area. The amounts of silver listed in some of the analyses in table 1 of this report warranted further investigation. Fire-assay data for eight samples selected from those collected at the deposit are shown in table 2. The sample numbers and material correspond to those in table 1. No specific gold or silver minerals were identified in this study.

Trace amounts of mercury were detected in all the samples from the barite deposit (table 1). Background values for the mercury content of rocks on the Seward Peninsula are less than 0.09 ppm. Thus, 10 of the samples, mostly those with abundant sulfide minerals, contain anomalous amounts of mercury. The samples of schist and marble in the mineralized area do not contain anomalous amounts of mercury. The anomalous amounts of mercury seem to accompany the lead and zinc minerals and barite, so geochemical prospecting with tests for lead-zinc or even barite could be successful and require less cost as well as less complicated techniques than prospecting with mercury.

Colloform calcite and aragonite with disseminated fine-grained galena and sphalerite constitute the principal filling of a group of west-trending veins that attain a maximum thickness of several inches. The veins were fractured and healed during the deposition of the carbonate minerals. Spectrographic analyses of samples from two of these veins are listed in table 1 (samples 13 and 24).

Table 1.—*Spectrographic analyses of samples from the Sinuk River barite deposit, Seward Peninsula, Alaska*

[Six-step semiquantitative spectrographic analyses by L.A. Bradley. Mercury determinations by J.B. McHugh by instrumental methods. G, amount greater than 10 percent; L, detected, but below limit of detection; N, not detected at limit of detection; ppm, parts per million (conversion 10,000 ppm = 1 percent). Asterisk (*) indicates sample in which additional elements were found (in ppm):

Sample 20: 50 B, 15 Co, 30 La, 15 Sc, 20 Ga.
21: 70 B, 15 Co, 70 La, 30 Sc, 150 Ce, 50 Ga, 100 Nd.
4: 70 La.
Sample 15: L B, 30 Cd.
14: 30 Cd, 3 Mo.
14A: 20 Co, 70 La, 15 Sc, 150 Ce.
14B: 2,000 As, 7 Mo, 30 Sn]

Material	Marble		Sericite schist	Chlorite schist	Barite			Breccia	Calcite	Aragonite	Fluorite	
Sample No....	7	18	*20	*21	3	25	8	22	13	24	*4	5
					Analyses in percent							
Si	1.5	0.5	G	G	0.05	0.2	1.5	2.0	L	0.007	0.05	0.02
Al	.15	.2	7.0	G	.002	.02	.005	.03	L	.02	.1	.1
Fe	.07	.07	5.0	7.0	.007	.05	.1	3.0	0.002	.1	.03	.007
Mg	.7	.2	.2	.7	L	.007	.005	7.0	.7	.02	.002	L
Ca	G	G	5.0	.7	.2	.7	2.0	G	G	G	G	G
Ti	.003	.005	.5	.1	N	L	N	L	L	N	.0005	L
					Analyses in parts per million							
Mn	100	30	500	300	30	7	50	700	5	5	50	30
Ag	N	N	N	N	N	N	N	3	N	1.5	N	N
Ba	150	30	700	3,000	G	G	G	30	70	150	700	200
Be	N	N	2	5	N	1.5	N	N	N	N	1.5	N
Cr	7	2	70	150	L	1	L	3	L	1	N	N
Cu	1	1	L	1.5	L	1.5	5	70	15	50	1.5	L
Nb	N	N	L	10	N	N	N	N	N	N	N	N
Ni	L	N	30	70	N	N	L	10	10	N	N	N
Pb	10	150	100	150	70	70	100	3,000	200	N	50	L
Sb	N	N	300	300	N	N	N	N	N	100	N	N
Sr	1,500	2,000	100	70	7,000	15,000	10,000	100	300	N	150	30
V	N	N	100	300	N	N	N	L	N	7,000	N	N
Y	N	N	30	70	N	N	N	N	N	N	70	150
Yb	N	N	5	N	N	N	N	N	N	N	3	3
Zn	N	N	N	200	N	N	N	2,000	5,000	1,500	N	N
Zr	N	20	200	500	N	N	N	N	N	N	N	N
Hg	.01	.03	.03	.04	.04	.44	.13	.25	.02	.03	.05	.02

Material	Fluorite					Quartz sulfides	Dolomite sulfides	Gossan	Calcite	Composite	Sheared rock	Vein
Sample No....	6	9	10	11	19	*15	17	23	1	*14	*14A	*14B
					Analyses in percent							
Si	0.02	0.07	0.05	0.02	0.01	G	1.0	0.5	0.07	0.7	3.0	G
Al	.1	.1	.15	.07	.15	0.02	.01	.3	.05	.07	.2	0.02
Fe	.01	.01	.005	.002	.005	.2	.1	G	.02	.7	G	.07
Mg	L	L	L	L	.005	.05	7.0	.2	.02	10.0	.005	.02
Ca	G	G	G	G	G	.15	7.0	7.0	G	G	G	.7
Ti	L	L	L	N	N	.0002	N	L	.001	.0002	L	L

Material	Fluorite					Quartz sulfides	Dolomite sulfides	Gossan	Calcite	Composite	Sheared rock	Vein
Sample No.	6	9	10	11	19	*15	17	23	1	*14	*14A	*14B
	Analyses in parts per million											
Mn	20	20	30	15	30	20	200	70	30	200	2,000	7
Ag	N	N	2	N	N	200	1.5	N	N	30	N	500
Ba	100	500	150	70	20	70	7	70	30	100	70	2,000
Be	1.5	N	N	N	N	N	N	N	N	N	3	N
Cr	N	N	N	N	N	L	7	7	L	3	1.5	5
Cu	L	L	1	N	L	100	10	30	1.5	150	500	700
Nb	N	N	N	N	N	L	L	L	N	L	L	L
Ni	N	L	N	N	N	N	5	30	L	7	15	L
Pb	10	20	100	N	150	G	1,000	700	15	G	5,000	G
Sb	N	N	N	N	N	1,500	150	150	N	50,000	N	G
Sr	30	50	20	70	20	10	50	30	2,000	100	150	100
V	N	N	N	N	N	N	N	N	N	10	30	L
Y	300	70	30	150	70	N	N	N	N	L	100	15
Yb	3	N	N	1.5	1	N	N	N	N	N	N	N
Zn	N	N	N	N	N	300	2,000	2,000	N	3,000	5,000	3,000
Zr	N	N	N	N	N	N	N	N	N	N	N	N
Hg	.02	.02	.13	.05	.02	3.0	.19	.84	.06	3.30	.63	.58

Sample description and locality

7. Calcite marble, upper bench.
18. Calcite marble, west side of lower bench.
20. Quartz-sericite schist, west side of middle bench.
21. Quartz-chlorite-sericite schist, west side of middle bench.
3. White barite, bulldozer cut northwest of main cut.
25. White barite, north end of upper bench.
8. White barite, folded into marble, upper bench.
22. Dolomite-calcite-quartz breccia, upper bench.
13. White colloform calcite, east-trending vein, south end of upper bench.
24. Pale-yellowish-green aragonite, east-trending vein, upper bench.
4. Purple fluorite, lower bench.
5. Light-purple fluorite, lower bench. Fluid inclusions studied in detail.
6. White fluorite, upper bench.
9. White fluorite, east side of upper bench.
10. White fluorite, collected about 6 feet north of sample 9.
11. Clear fluorite, upper bench.
19. Deep-purple fluorite clots in iron-stained schist near west side of north end of upper bench.
15. Quartz-sulfide mass, east side of middle bench.
17. Dolomite with sulfide veinlets, east side of middle bench.
23. Gossan (goethite-calcite rock), upper bench.
1. White calcite, vein on lower bench.
14. Composite of sheared fluorite rock and unsheared vein, east side of middle bench.
14A. Sheared rock with fluorite, calcite, quartz, and goethite at edge of vein; locality same as for 14.
14B. Sulfide minerals and quartz from center of vein; locality same as for 14.

Table 2.—*Fire assay values of selected samples from the Sinuk River barite deposit, Seward Peninsula, Alaska*

[Gold determined by fire assay plus atomic absorption method by W. D. Goss, A. W. Haubert, and J. A. Thomas. Silver determined by fire-assay difference method by L. B. Riley]

Sample No.	Material	Gold		Silver	
		(ppm)	(oz per ton)	(ppm)	(oz per ton)
8.	White barite	<0.05	...	...	....
10.	Fluorite	<.05	...	...	....
14.	Composite of sheared rock and unsheared vein	.2	<0.1	260	7.65
15.	Quartz-sulfide mass	3.6	.1	155	4.55
17.	Dolomite	<.05	...	...	....
22.	Dolomite breccia	<.05	...	...	....
23.	Gossan	<.05	...	...	....
25.	White barite	.8	<.1	...	....

GOSSAN

A small gossan is exposed on the upper bench. The material looks dense, but it contains a few percent, by volume, of tiny cavities which are lined with calcite. Thin-section and X-ray studies show that the material is chiefly goethite, which is both very fine grained and well crystallized. A sample of this material contains 2,000 ppm zinc and a little lead and copper (table 1, sample 23). The lead and zinc content in the gossan material is roughly comparable to that in the analysis of the sulfide materials shown in table 1.

Pyrite (FeS_2) is a common accessory mineral disseminated through many rocks at the deposit, and some also is associated with galena. There is no evidence, however, to suggest either that large amounts of pyrite were introduced to the area or that the goethite-rich gossan was derived from pyrite.

FLUID INCLUSIONS

Fluid inclusions are abundant in all the fluorite that was studied. Slices of fluorite about 2 mm thick were cut and polished on both sides. These slices were examined under a microscope equipped with a heating stage and a device to record temperatures.

The inclusions are of two kinds, those along healed fracture planes and those along the grain boundaries of recrystallized fluorite. The inclusions along the healed fracture planes are mostly equidimensional and have negative crystal faces, as though they may be primary inclusions; that is, fluid trapped along crystal faces while the fluorite was being deposited. The planes defined by these inclusions, however, seem to be curved and do not meet at right angles. Thus, they are fracture planes in massive fluorite and not crystallographic planes, and these inclusions are of secondary origin.

Fluid inclusions of the second type—those along the grain boundaries of recrystallized fluorite—are extremely thin and irregular in shape. They lie along curved planes of ellipsoidal shape, between which are zones of clear fluorite that contains no fluid inclusions. The three-dimensional aspect of the ellipsoid is clearly seen by raising or lowering the focal plane of the microscope through the polished plate. These fluid inclusions are along grain surfaces of the granulated and recrystallized (healed) fluorite described above, and the fluids probably were trapped during recrystallization of the fluorite.

The fluids in both types of inclusions consist of three phases—liquid water, liquid carbon dioxide, and gas. The carbon dioxide was identified by warming and cooling the inclusion to temperatures above and below the critical temperature (31.1°C) of carbon dioxide and observing the disappearance and reappearance of the carbon dioxide phase.

The filling temperatures of eight inclusions were determined by heating each sample until the gas bubble disappeared in a homogenized liquid phase and then cooling the sample until the bubble reappeared. The measurements obtained are shown in figure 2. Three of the inclusions studied were among those that surround clear granules of fluorite, and the other five were among those along the healed fracture planes. Seven of the inclusions filled at 243°±6°C, and the other inclusion filled between 255° and 256°C. The uncertainty in the filling temperature is the result of poor optical properties of the inclusions rather than erratic behavior during the heating experiments. The temperatures given are a reasonable approximation of the temperature that prevailed when the deposits were recrystallized and later fractured. A more accurate estimate of the temperature would have to take into account corrections for the salinity of the fluid and the pressure that prevailed when the fluids were trapped. The data for such corrections are not available, but the corrections, if applied, probably would not significantly affect the conclusions.

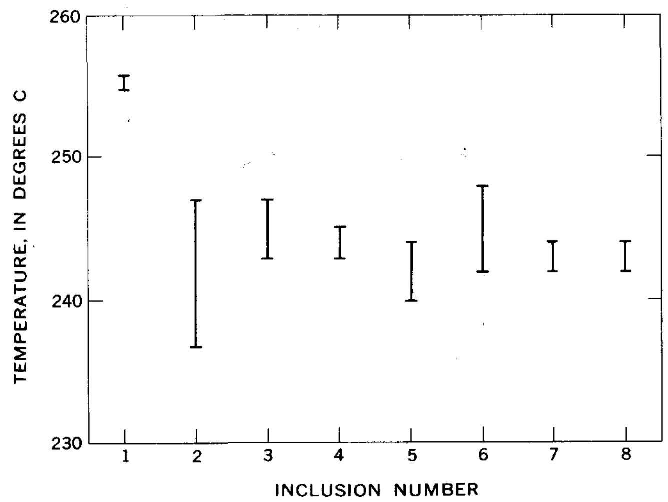

Figure 2.—Filling temperatures of fluid inclusions in fluorite. The fluid inclusions, upon heating, converted to a single phase (liquid) at the temperature shown by the vertical bars. Inclusions 1–3 are along grain boundaries of recrystallized fluorite; inclusions 4–8 are along fracture planes in fluorite.

The composition of the fluid inclusions was determined in order to estimate the pressure that prevailed and, therefore, the minimum depth of cover in the area when the inclusions were trapped. The carbon dioxide and water were extracted from the fluid inclusions in a sample of fluorite. The fluorite was cut into thin slabs, polished on both sides, and examined microscopically for fluid inclusions showing three phases. The slabs were soaked in hydrochloric acid to remove any traces of calcite from the small veinlets mentioned above. The slabs were then placed in an evacuated chamber in a furnace and heated to 425°C to rupture the inclusions and release the water and carbon dioxide. Experiments showed that calcite, if present, would not release carbon dioxide at this temperature. The released gases were passed into a vacuum line, which is designed specifically to separate carbon dioxide and water, and the amounts of carbon dioxide and water were measured. The fluid recovered consists of 3.2 mole percent carbon dioxide. According to the data of Takenouchi and Kennedy (1964), a mixture of this composition exerts a pressure of 233 bars at 250°C. This pressure is equivalent to that exerted by a column of water about 7,900 feet in height or by a column of rock (density 2.6) about 3,000 feet in height. From these data, the depth of the deposit at the time of recrystallization of the fluorite is estimated to have been at least a few thousand feet.

INTERPRETATIONS

The significance of the observations at the Sinuk River barite deposit may be evaluated by synthesizing the events in the geologic history in the area and relating them to the events in the geologic history of the Seward Peninsula.

At the barite deposit, originally layered rocks were metamorphosed (recrystallized and foliated) into a sequence of marble and micaceous schist. These rocks were then deformed, the compositional layers and the micaceous minerals within them were folded and partly fractured, and southerly trending linear structures were developed. Solutions entered the country rocks pervasively and deposited fluorite, barite, sulfide minerals, and some precious metals along the foliation planes and contacts between schist and marble. Some of the introduced material was partly sheared and recrystallized under a pressure equivalent to a cover of a few thousand feet of rock and at a temperature of about 250°C, as indicated by the fluid inclusions in the fluorite. Later, some thin, steeply dipping veins were filled with carbonate and some metal sulfides. These late veins trend west, across the preexisting structures of the metamorphic rocks.

A considerable amount of information on the rocks, geologic structure, and history of the Seward Peninsula has been outlined by Sainsbury, Coleman, and Kachadoorian (1970), and is summarized below. Among the younger, but not the youngest, rocks of Precambrian age is a sequence of marble and schist called the Nome Group, which is exposed in thrust sheets that occupy more than 10,000 square miles of the peninsula. The rocks of the Nome Group have been through two cycles of thrusting, the earlier characterized by intense folding and eastward transport, and the later characterized by imbricate thrusting, without folding, and northward transport. The thrusting was completed before middle Cretaceous time; the thrust sheets have been intruded by granites of middle Cretaceous age (100 m.y. years ago). Associated with these granites is a regional thermal metamorphism that generated the retrograde metamorphic effects in the blueschist facies so common in the rocks of the Nome Group. In latest Cretaceous, or earliest Tertiary time, about 74 m.y. ago, more bodies of granite intruded the Seward Peninsula. These intrusive rocks have associated ore deposits containing tin, lead, zinc, and fluorite that were introduced into the country rocks in a largely pervasive manner, rather than as vein fillings. Later in Tertiary time, another group of igneous rocks was emplaced. Ores associated with these rocks are fissure-filling deposits containing gold, silver, and antimony. These deposits, notably lacking in fluorite, are the source of some of the gold mined from the famous placer deposits of the Nome district.

The rocks at the barite deposit are mineralogically similar to other rocks of the Nome Group on the Seward Peninsula, and they display other characteristics of folding, metamorphism, shear, and even a southward-plunging lineation attributable to northward transport. Because of these similarities, we assign the rocks to the Nome Group.

Continued study of the Seward Peninsula shows that the structure of the Nome region is even more complex than formerly realized. Preliminary geologic maps of the Nome C-1 and Nome D-1 quadrangles (Hummel, 1962a, b), which lie about 10 miles east of the barite deposit (fig. 1), show many faulted areas consisting of markedly different metamorphosed rocks, all designated as Paleozoic in age. In the Nome D-1 quadrangle, the difference between the rocks north and south of the Stewart River suggests that each area could be interpreted as a different thrust sheet whose boundary fault may lie in the valley of the Stewart River. The blue-gray marble and micaceous schists south of the Stewart River have the same characteristics as those rocks at the barite deposit. Thrust sheets involving rocks of the Nome Group probably do extend into the Nome region of the Seward Peninsula.

If the assumption is correctly made that the metamorphic rocks exposed at the barite deposit are part of the Nome Group, then these rocks have been involved in the two cycles of thrusting and the mid-Cretaceous thermal metamorphism. Thus, the folding in the country rocks at the barite deposit probably resulted from the movements in the first cycle of thrusting; and the south-plunging lineations probably resulted from movements in the second cycle. The retrograde metamorphic effects, including the development of some of the sericite and chlorite, resulted from the thermal metamorphism during the emplacement of bodies of mid-Cretaceous granite, some of which pierced the core of the Kigluaik Mountains about 20 miles north of the barite deposit.

The suite of minerals, including fluorite, barite, and metal sulfides, was introduced to the host rocks by a process of impregnation that seems best correlated with the pervasive mineralization characteristic of that associated with the emplacement of tin-bearing granites, about 74 m.y. ago.

After the introduction of these minerals, they were recrystallized in the presence of carbon dioxide-rich solutions at moderately high temperature (about 250°C). The recrystallization may have occurred late in the original cycle of mineralization or in a later cycle of hydrothermal activity, such as that which produced the later Tertiary fissure veins containing the gold, silver, and antimony in the rocks of other nearby thrust sheets.

The steeply dipping, west-trending fissure veins of calcite and aragonite, with accessory amounts of base and precious metals, were emplaced later than the impregnating fluorite, barite, and sulfide minerals. These vein fillings are not sheared, but the colloform structures are broken and healed, suggesting that the area of emplacement was then under tension and not compression as it probably was during the time of major fluorite-barite mineralization. These veins are perhaps related to later Tertiary fissure-filling deposits.

The precious metals and antimony are characteristic of the suite of minerals associated with the later Tertiary vein fillings, but not necessarily exclusively so. Gold and silver are detected in areas mineralized by the impregnations associated with the 74-m.y.-old bodies of granite. The presence, however, of seemingly unsheared galena and boulangerite with associated silver and gold, along with fluorite recrystallized at about 250°C at the barite deposit, allows for the possibility that the rocks of the Nome Group in this thrust sheet were mineralized more than once.

CONCLUSIONS

In conclusion, we are suggesting that the area is an attractive target for further exploration for mineral deposits of commercial value.

The complex folding and faulting of several ages in a large area suggests that channels for entry and dispersion of ore-depositing solutions through sheets of foliated rocks probably have been opened during several intervals since Precambrian time.

The occurrence of pervasively disseminated fluorite, barite, and sulfides of lead, zinc, and antimony with associated silver and gold, and anomalous amounts of mercury at the barite deposit suggests that the major mineralization belongs to that associated with the emplacement of the bodies of tin-bearing granite in the Seward Peninsula, about 74 m.y. ago.

The temperature of homogenization of the fluid included in the fluorite (243°±6°C) suggests that sources of hot solutions were nearby, at least once, and that hydrothermal ore deposits displaying the classic features of mineral zonation may occur in the area. The fluorite is partly sheared and recrystallized, events which might have occurred late in the cycle of original deposition or even later. The fluorite certainly was not completely sheared and recrystallized after the entrapment of the fluids. Mineralization might have occurred in more than one cycle of activity.

The vertical and lateral extent of the mineralized rock exposed at the barite deposit is unknown. The structural and lithologic controls of the mineralizing solutions clearly involve the marble exposed in the area. Other marble, which could also be mineralized, may be inferred at depth. Mineralization might have taken place only in the shear zones between the thrust sheets or might have penetrated favorable host rocks in both the overriding and underlying sheets.

Further exploration in this area seems warranted.

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CRETACEOUS PLUTONIC ROCKS OF ST. LAWRENCE ISLAND, ALASKA—A PRELIMINARY REPORT

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Abstract.—Reconnaissance mapping on St. Lawrence Island, Alaska, has revealed seven epizonal granitic plutons of middle Cretaceous age with a combined outcrop area of about 350 square miles. The plutonic rocks are dominantly quartz monzonite but include minor amounts of granodiorite, monzonite, syenite, syenodiorite, and alaskite. Plutons on the Chukotsky Peninsula, U.S.S.R., and in western Alaska are similar to these in structure, petrology, and age. The St. Lawrence Island plutons may thus provide evidence of tectonic continuity between Siberia and Alaska since at least Cretaceous time. Several mineralized areas containing molybdenum, copper, lead, and zinc sulfides are associated with the plutonic bodies in the western part of the island.

This report is a preliminary description of the petrology, age, and regional relations of seven granitic plutons mapped during reconnaissance geologic investigations on St. Lawrence Island, Alaska.

St. Lawrence Island, roughly 2,000 square miles in area, is in the Bering Sea, 130 miles southwest of the Seward Peninsula and 40 miles southeast of the Chukotsky Peninsula, U.S.S.R. (fig. 1). About two-thirds of the island is a tundra-covered flat wave-cut platform which has been elevated locally as much as 200 feet above sea level. The remainder consists of isolated groups of barren, talus- and rubble-covered mountains, most of which have cores of granitic rock. Probably former islands, they rise sharply 1,000 to 2,000 feet above the wave-cut platform. Bedrock exposures are scarce and are confined to coastal sea cliffs, scattered cutbanks along streams, and a few erosional knobs in the mountainous areas.

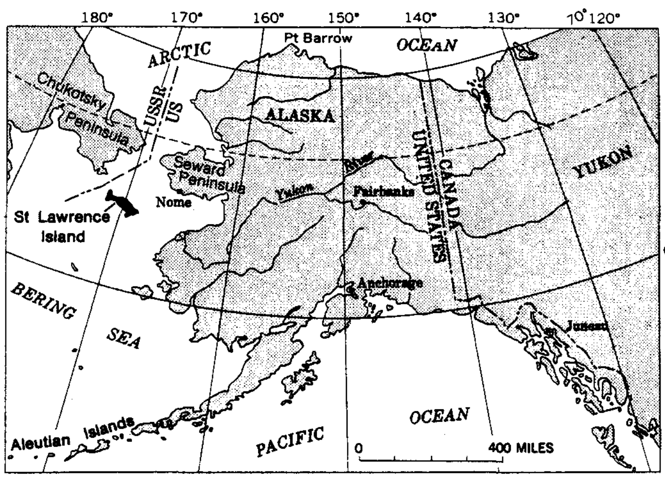

Figure 1.—Index map of Alaska, showing location of St. Lawrence Island.

Previous information on the geology of St. Lawrence Island consists of exploratory surveys along the coast (Dawson, 1894; Emerson, 1904, p. 38–42; Collier, 1906), an unpublished reconnaissance map compiled by E. H. Muller (*in* Dutro and Payne, 1957), two short preliminary papers on the eastern part of the island (Patton and Dutro, 1969; Patton and Csejtey, 1971b), and two preliminary reports on the western part of the island (Patton and Csejtey, 1970, 1971a).

GEOLOGIC SETTING

The St. Lawrence plutons range in areal extent from 1 to 100 square miles and have a total outcrop area of about 350 square miles (fig. 2). However, they undoubtedly extend beneath surrounding surficial deposits and the Bering Sea and are probably larger than the above figures indicate.

The contacts between plutons and country rocks are sharp, steep, and apparently discordant wherever observed. The country rocks are dominantly Paleozoic carbonates and andesitic volcanic rocks of Early Cretaceous(?) age; also, there are lesser amounts of mudstone, graywacke, chert, gabbro, and diabase (fig. 2). The andesites are mapped with postplutonic latites and quartz latites of Late Cretaceous and early Tertiary age because both volcanic suites have numerous varieties, are finely crystalline, and are strongly altered. The lithology, age, and correlation of these rocks have been discussed previously by Patton and Dutro (1969), and by Patton and Csejtey (1971a, b).

Postplutonic rocks include poorly consolidated middle Tertiary coal-bearing strata in a few small areas (not shown on fig. 2), Quaternary olivine basalts (mostly in the centrally

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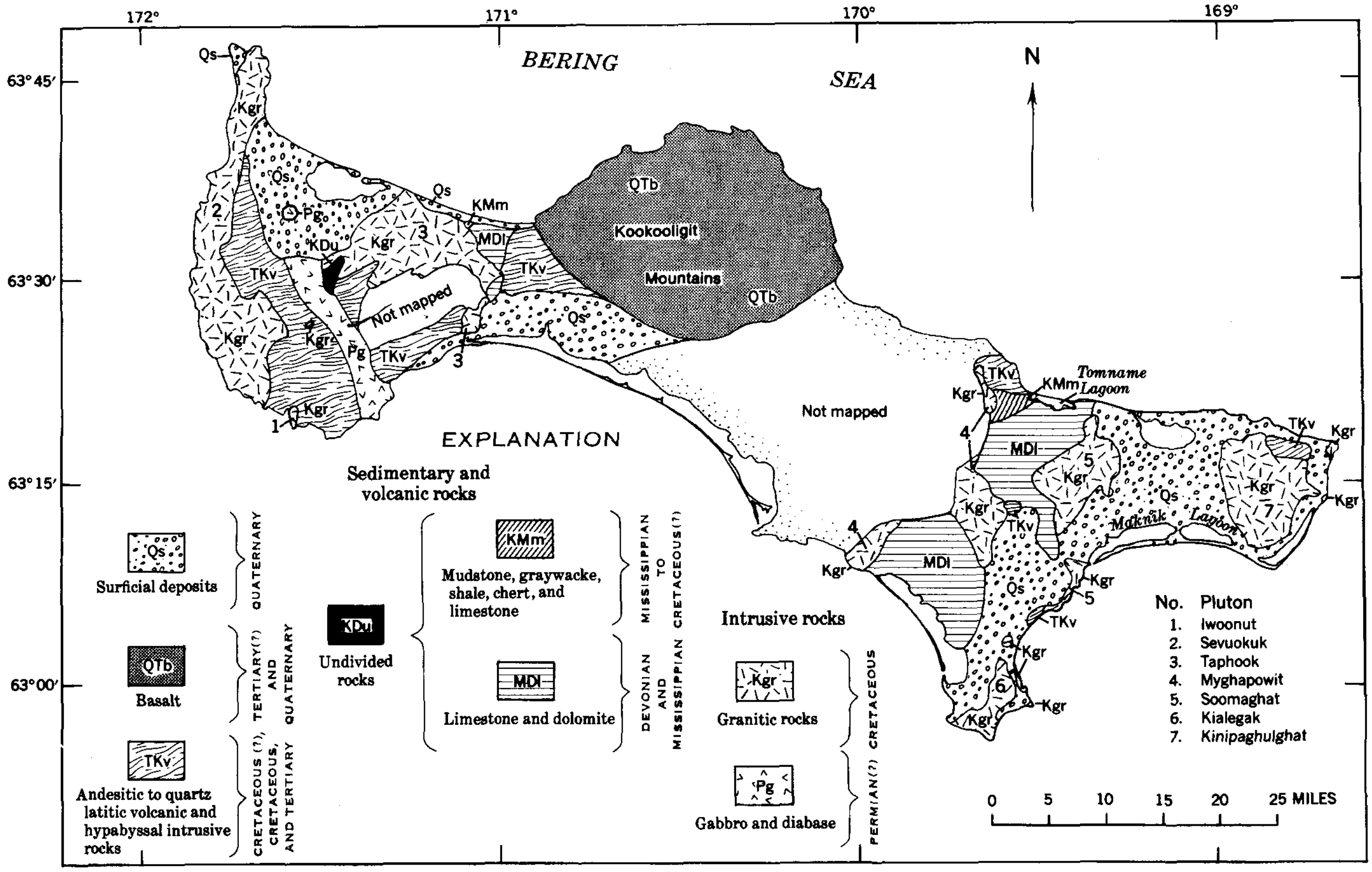


Figure 2.—Generalized geologic map of St. Lawrence Island, Alaska, showing location of plutons.

located Kookooligit Mountains), and extensive unconsolidated surficial deposits.

The plutons appear to truncate steeply dipping beds and several faults in the country rocks and thus may have been emplaced in an already folded and faulted terrane. The postplutonic latites and quartz latites were folded and faulted in Late Cretaceous and Tertiary time.

Thermal metamorphic effects extend as much as a mile into the country rocks. However, the width of the metamorphosed zone in the volcanic rocks is difficult to determine because most of the volcanic rocks have been propylitically altered. Near the intrusive contacts and locally extending out for some tens of feet, the rocks are altered to hornblende hornfels (Fyfe and others, 1958). The carbonate rocks are characterized by a mineral assemblage of garnet-vesuvianite-diopside-quartz-calcite-biotite. The andesitic volcanic rocks are characterized by an assemblage of plagioclase-hornblende-quartz-biotite. Farther away, the volcanic rocks are mostly albite-epidote hornfels; the carbonates are medium-grained marble.

PLUTONIC ROCKS

Petrography and petrology

The plutonic rocks of St. Lawrence Island are chiefly quartz monzonite but include granodiorite, monzonite, syenite, alaskite, and some olivine-bearing syenodiorite. The classification of plutonic rocks used in this report, based on the normalized modes of felsic components, is shown in figure 3. Textural variations range from coarse to fine grained, from granitic to porphyritic and seriate. All the plutonic rocks are massive and nonfoliated. Hybrid rocks rich in mafic minerals and of irregular texture occur in minor amounts near the margins of some plutons.

The modes of 36 plutonic rock specimens from western St. Lawrence Island and of 49 specimens from the eastern part of the island are plotted separately on figure 4. Both plots show a fair concentration of points in the quartz monzonite-granodiorite fields, and a lesser concentration in the monzonite-syenite fields. The quartz monzonites and granodiorites constitute distinct intrusive masses within the large composite plutons. Boundaries between them appear to be sharp and can be traced over long distances. Several of these intrusive members display a fine- to medium-grained border phase, not only against the volcanic and sedimentary country rocks but against other plutonic rocks as well.

The intrusive relationships between the various intrusive members are not clear everywhere. Where such relationships can be determined, quartz-rich rocks intrude rocks of lesser quartz and higher mafic mineral contents, suggesting a magmatic trend from older quartz-poor rocks to younger,

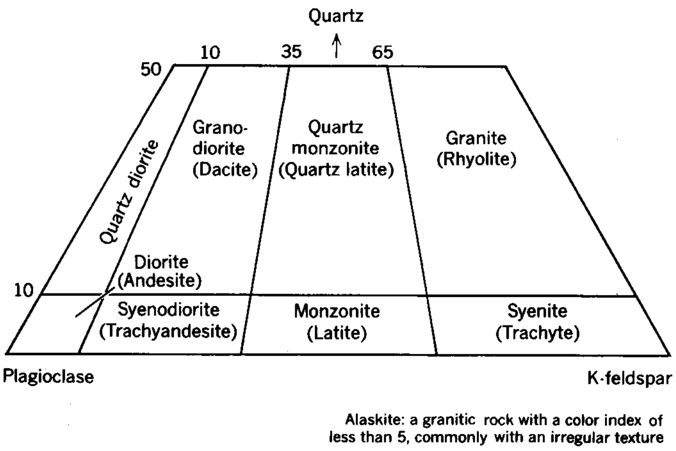


Figure 3.—Igneous rock nomenclature used in this report. Aphanitic varieties shown in parentheses.

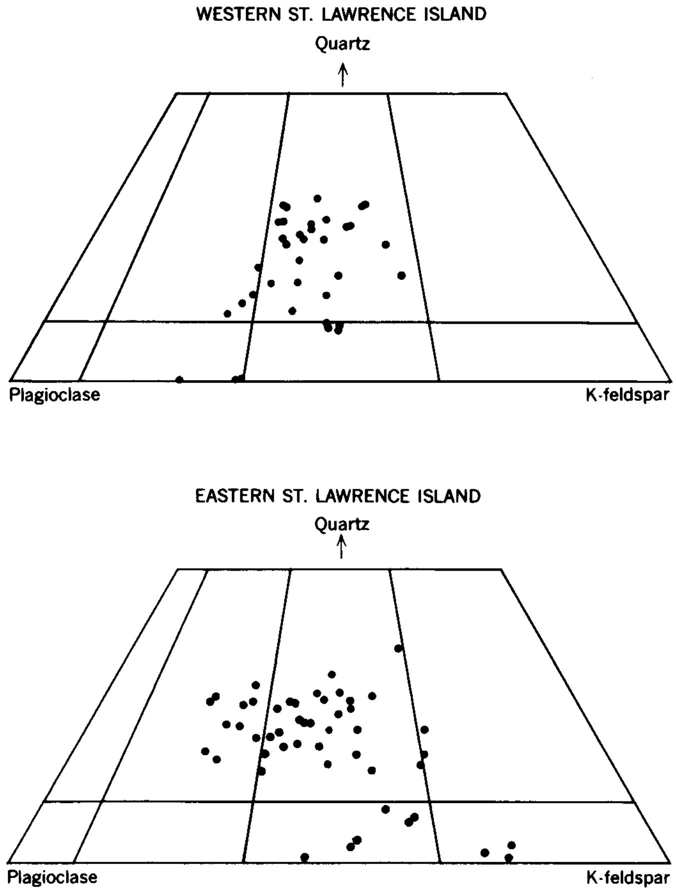


Figure 4.—Summarized plots of plutonic rock modes from western and eastern St. Lawrence Island, Alaska. See table 1 for plots of individual plutons.

more felsic rocks.

The petrography of the plutons is summarized in table 1, and maps of the plutons are shown on figures 5 and 6. Field mapping of the various intrusive members was based on the characteristic features listed at the bottom of table 1. Rocks of the Iwoonut, Sevuokuk, and Taphook plutons have been previously described by Patton and Csejtey (1971a). The olivine-bearing monzonite of that report is herein reclassified, on the basis of additional modal data, as an olivine-bearing syenodiorite.

The St. Lawrence plutonic rocks fall more or less into three major categories: (1) monzonites and syenites, including the olivine-bearing syenodiorite, containing abundant mafic minerals but little or no quartz; (2) quartz monzonites, locally grading into monzonites and granodiorites, with an intermediate amount of quartz and with hornblende as the chief mafic mineral; and (3) quartz monzonites, locally grading into granodiorite and alaskite, which have a high quartz content and lower color index with biotite as the chief mafic mineral. These three groups of rocks are thought to represent the three major magmas, emplaced in a succession, of the middle Cretaceous plutonic episode of St. Lawrence Island.

Dike rocks and xenoliths

All the plutons contain a large number of dikes and small plugs of a variety of late-stage rocks—namely, aplite and alaskite, lamprophyre, hypabyssal felsic porphyries, and a few thin veins of hydrothermal quartz. The age relationships of these dike rocks are not known, and only the larger bodies have been mapped (figs. 5 and 6).

The aplites are fine grained and commonly grade into medium- to coarse-grained irregular-textured alaskite, occasionally with miarolitic cavities. The aplitic rocks rarely grade into coarse-grained pegmatitic nests of K-feldspar, quartz, and muscovite. These rocks occur in thin dikes and in small intrusive bodies as much as 1 square mile in area. Whereas aplites are common in all the plutons, they rarely extend into the surrounding country rocks.

Irregular dikes of lamprophyre, a few inches to a few feet in width, are common in the northern half of the Sevuokuk pluton. The lamprophyre is dark gray and porphyritic, with dark hornblende phenocrysts as much as 3 mm long in a finely crystalline, lamprophyric-textured matrix of brown hornblende, plagioclase, and minor augite.

The felsic porphyries common in every pluton occur as irregular hypabyssal bodies up to 2 square miles in area and intrude both the plutonic and the country rocks. The porphyries range from latite to quartz latite in composition and contain large phenocrysts of corroded quartz and subhedral K-feldspar in a medium- to light-gray aphanitic groundmass. Miarolitic cavities are common. Most of the porphyries are altered to an aggregate of quartz, sericite, kaolin, and pyrite, with minor amounts of chlorite and epidote. These hypabyssal felsic porphyries are probably the source of the latite and quartz latite volcanic rocks of Late Cretaceous and early Tertiary age.

Xenoliths are common in the coarse- and medium-grained rocks. Most xenoliths are rounded and equant, a few inches to

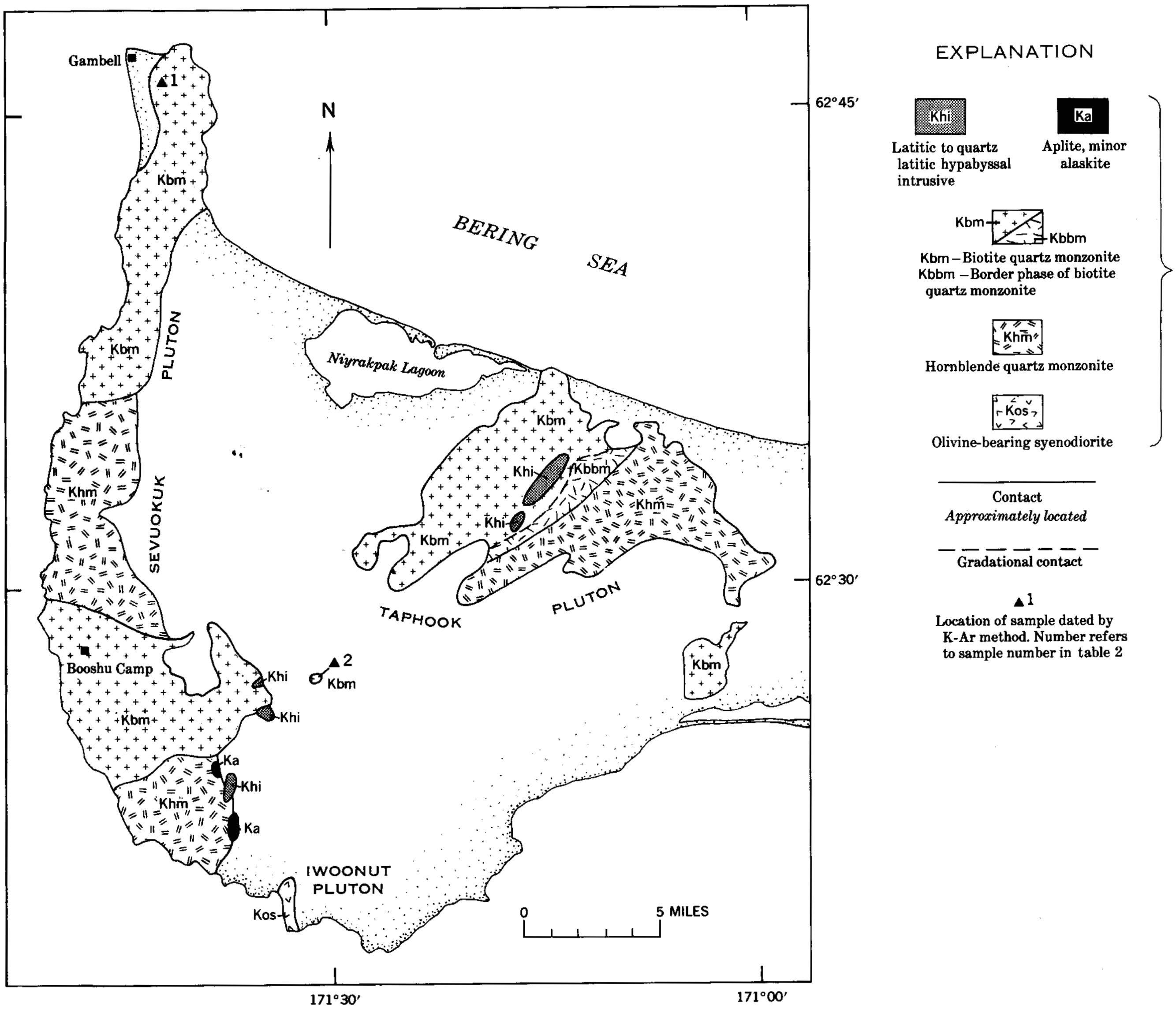


Figure 5.—Generalized geologic map of the Iwoonut, Sevuokuk, and Taphook plutons, western St. Lawrence Island, Alaska.

about 1 foot long, with fairly sharp boundaries; all have been reconstituted to a fine- to medium-grained, hornblende-rich hornfels. Several apparent roof pendants of recrystallized Paleozoic limestone, a few tens of feet in maximum dimension, occur in the Soomaghat and Kinipaghulghat plutons.

Structural features

All the plutons appear to be jointed, but few joint measurements could be obtained because of scarcity of bedrock exposures. Two sets of vertical joints striking northeast and northwest are conspicuous in every coastline exposure of the Sevuokuk pluton.

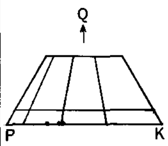
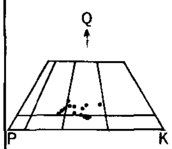
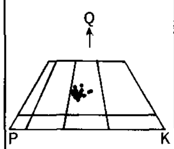
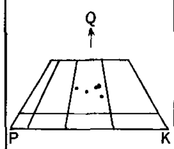
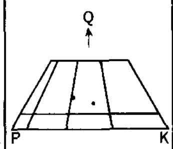
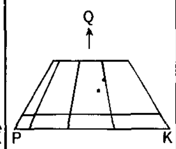
One of the major characteristics of the St. Lawrence plutons is the absence of obvious regional foliation and lineation. Structural features—localized flow alinement of orthoclase phenocrysts—were observed only in the Soomaghat and Sevuokuk plutons. Because most rock specimens were collected as float, no attempt was made to find preferred orientation by petrofabric measurements with thin sections.

Depth and method of pluton emplacement

The structure and the petrography of the plutons suggest that the plutons were emplaced at relatively shallow depths in the earth's crust. The St. Lawrence plutons are epizonal, according to the usage of Buddington (1959), on the basis of the following features: sharp and discordant contacts with the regionally unmetamorphosed country rocks, presence of chilled border facies, presence of xenoliths and apparent roof

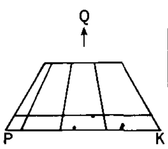
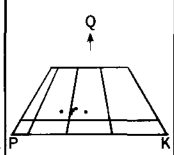
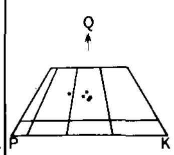
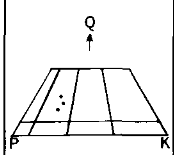
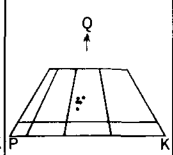
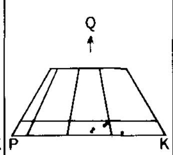
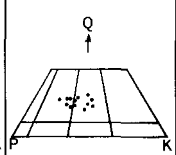
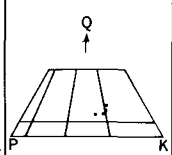
Table 1.—*Petrographic summary of the Cretaceous granitic plutons of St. Lawrence Island, Alaska*

[Intrusive members of each pluton are listed in order of decreasing age, known or postulated]

	Name and outcrop area of pluton	IWOONUT PLUTON ~ 1 mi^2	SEVUOKUK PLUTON ~ 100 mi^2		TAPHOOK PLUTON ~ 70 mi^2		MYGHAPOWIT PLUTON* ~ 40 mi^2	
	Lithology of intrusive members	Olivine-bearing syenodiorite	Hornblende quartz monzonite. Also granodiorite and monzonite	Biotite quartz monzonite. Also alaskite	Hornblende quartz monzonite	Biotite quartz monzonite. Also alaskite	Porphyritic hornblende quartz monzonite	Biotite quartz monzonite. Also alaskite
	Color index	10-18	8-27	4-14	Est. 10-15	3-11	6-7	3-6
Composition[1]	Quartz in volume %	None	7-17	19-31	Est. 10-15	21-30	17-19	27-36
Composition[1]	Mafic minerals; modal ranges in volume %	Augite 4-10 biotite 3-7 olivine 1-3	Hornblende 4-17 biotite 0-10 clinopyroxene < 1	Biotite 2-14 hornblende 0-6	Hornblende biotite	Biotite 3-8 hornblende 0-4	Hornblende 3-4 biotite 3-4	Biotite 3-5 hornblende 0-2
Composition[1]	Plagioclase composition	Sodic labradorite-calcic andesine	Sodic andesine-calcic oligoclase	Oligoclase-albite	Sodic andesine-calcic oligoclase	Oligoclase	Sodic andesine-calcic oligoclase	Oligoclase
Composition[1]	Ubiquitous accessories	Apatite, zircon, magnetite	Sphene, apatite, magnetite, zircon		Sphene, apatite, magnetite, zircon		Sphene, magnetite, zircon, apatite	
Composition[1]	Other accessories			Allanite				
Composition[1]	Modal composition (See also fig. 3)				No modal analyses available			
Texture	Grain size	Coarse to medium	Medium to coarse	Coarse to medium	Medium	Coarse to fine	Coarse to medium	Coarse to fine
Texture	Fabric	Granitic	Granitic to slightly porphyritic	Granitic to porphyritic and seriate	Granitic	Porphyritic to granitic	Porphyritic to seriate	Granitic
	Progressive normal zoning of plagioclase	Rare	Common	Common and strong	Common	Common but faint	Common	Common
	Remarks	Olivine poikilitic in feldspars, partly altered to magnetite and biotite	Myrmekitic intergrowth of quartz and plagioclase common. Pyroxene as relict core in hornblende	Sparse microcline	Sericitization and chloritization are intense and widespread	Occasional microcline. Fine-grained border phase against hornblende quartz monzonite member	*Only partly mapped. Finer grained border phases are common	Fine-grained border phase against porphyritic hornblende quartz monzonite
	Characteristic feature	Reddish biotite. Medium- to dark-greenish-gray color	Low quartz content, abundance of hornblende.	High quartz content; dark-gray quartz anhedra. Scattered orthoclase phenocrysts.	Low quartz content, abundance of hornblende	Porphyritic texture with orthoclase phenocrysts. High quartz content.	Porphyritic texture with large twinned orthoclase crystals	Large dark-gray smoky quartz anhedra

1 During the course of the present study, approximately 300 thin sections were examined. A total of 85 modal analyses was obtained by point counts on sawed slabs stained by sodium cobaltinitrate. Between 600 and 1,000 points were counted on each slab.

Table 1. – Continued

SOOMAGHAT PLUTON ~ 45 mi²			KIALEGAK PLUTON ~ 30 mi²		KINIPAGHULGHAT PLUTON ~ 65 mi²		
Monzonite-syenite	Porphyritic hornblende quartz monzonite. Also granodiorite	Biotite quartz monzonite. Also alaskite	Biotite granodiorite	Biotite quartz monzonite	Monzonite-syenite	Biotite quartz monzonite. Also granodiorite and alaskite	Quartz monzonite-alaskite
6-20	5-9	2-11	9-19	7-10	14-30	3-12	2-8
1-3	14-19	24-30	15-26	18-26	1-6	18-29	14-23
Hornblende 6-13 biotite 0-7 clinopyroxene < 1	Hornblende 3-7 biotite 1-3	Biotite 2-11 hornblende 0-1	Biotite 5-13 hornblende 2-7	Biotite 4-9 hornblende 0-4	Hornblende 11-29 biotite 1-11	Biotite 3-9 hornblende 0-2	Biotite 2-7 hornblende 0-2
Sodic andesine-calcic oligoclase	Andesine-sodic oligoclase	Oligoclase	Sodic andesine-calcic oligoclase	Oligoclase	Sodic andesine-calcic oligoclase	Oligoclase-sodic andesine	Sodic andesine-oligoclase
Sphene, magnetite, apatite, zircon			Sphene, magnetite, apatite, zircon		Sphene, apatite, magnetite, zircon		
Tourmaline		Allanite				Allanite	Allanite
							
Coarse to medium	Medium to coarse	Coarse to medium	Medium	Coarse to medium	Coarse to medium	Coarse to fine	Fine to medium
Porphyritic to granitic	Porphyritic to seriate	Granitic to seriate	Granitic to seriate	Granitic to seriate	Porphyritic	Granitic to seriate	Seriate to granitic and irregular
Common	Common and strong	Common	Common	Common	Common	Common	Common
Clinopyroxene occurs as relict core in hornblende	Orthoclase poikilitically engulfing other minerals	Some microcline. Quartz generally occurs in sutured mosaics with undulating extinction	Myrmekitic intergrowths of orthoclase and oligoclase	Medium-grained border phase against biotite granodiorite. Some dark hybrid rocks	Orthoclase phenocrysts enclosing other minerals. Myrmekitic intergrowths or orthoclase and plagioclase	Some microcline. Fine-to medium-grained border phase against monzonite-syenite unit.	Some microcline. Alteration to sericite, chlorite, and some epidote is intense
Dark-gray color, porphyritic texture with large twinned orthoclase phenocrysts	Porphyritic texture with large twinned orthoclase	Coarse texture. Large dark-gray smoky quartz anhedra	Medium grain size, medium- to dark-gray color	Coarse to medium grain size, large dark-gray smoky quartz anhedra	Porphyritic texture with large orthoclase crystals, dark- to medium-gray color	Generally coarse texture, large dark-gray smoky quartz anhedra	Medium- to dark-gray color, generally fine-grained texture.

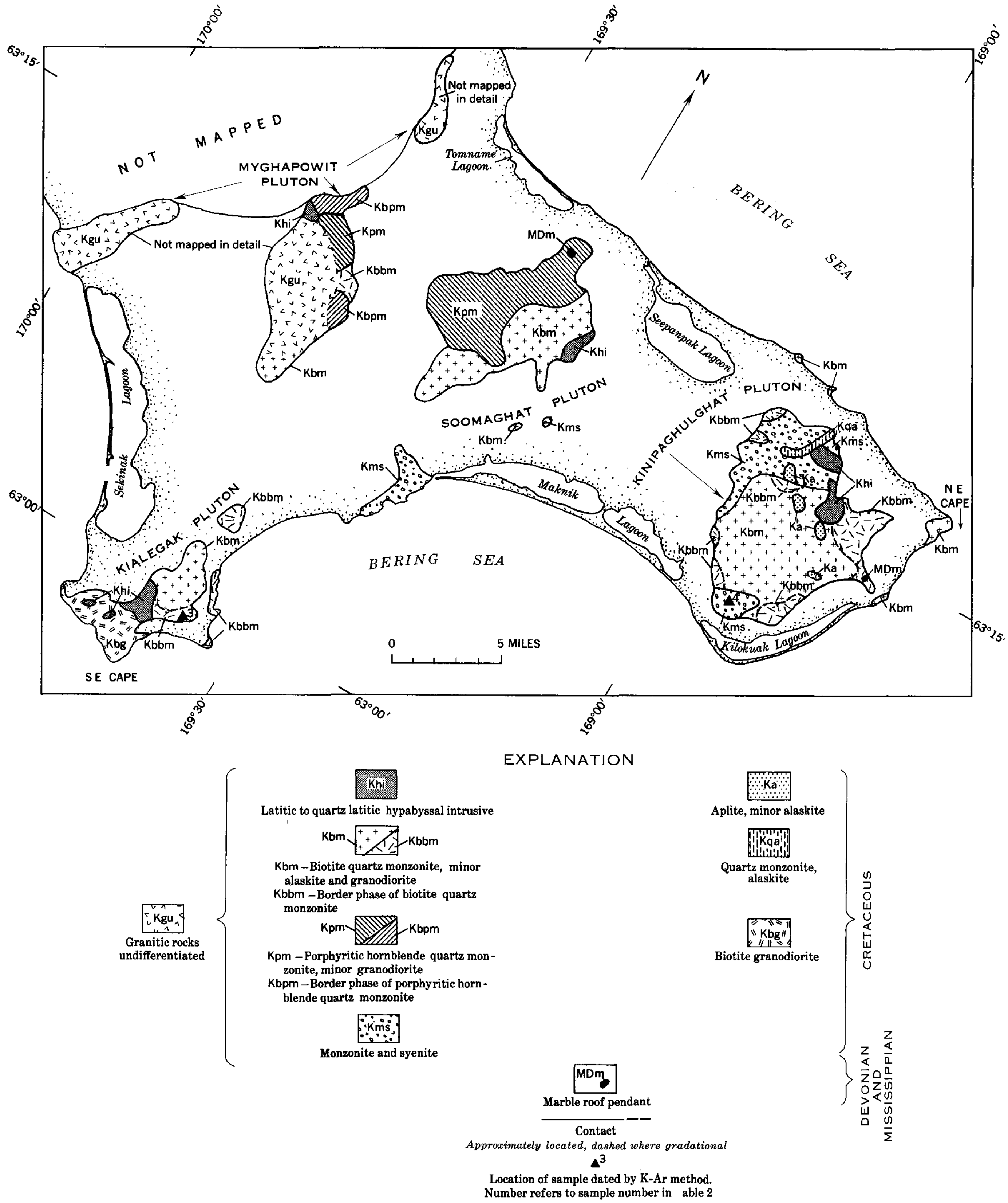


Figure 6.—Generalized geologic map of the Myghapowit, Soomaghat, Kialegak, and Kinipaghulghat plutons, eastern St. Lawrence Island, Alaska.

pendants, lack of regional foliation and lineation, and association with compositionally similar hypabyssal volcanic intrusives which commonly contain miarolitic cavities.

The plutons were emplaced by successive injections of apparently consanguineous magmas of diverse composition. The method of magma emplacement is not known. There is no evidence that the intrusions deformed the country rocks.

Mineralization

Several small mineralized areas of molybdenum, copper, lead, and zinc sulfides occur in and around the granitic plutons in the western part of the island. They have been described previously by Patton and Csejtey (1970, 1971a) and are only briefly mentioned here.

Molybdenite is widely disseminated in the Sevuokuk pluton. A small mineralized satellitic stock of biotite quartz monzonite, containing low-grade porphyry copper and minor molybdenite, is located approximately 8 miles east-southeast of Booshu Camp (fig. 5). Five small occurrences of lead-zinc-silver sulfides were found along a northeast-trending belt south and east of the Taphook pluton.

Similar mineralized areas have not been found in the eastern part of the island (Patton and Csejtey, 1971b). However, tin was detected in stream-sediment samples from streams draining the Soomaghat and Kinipaghulghat plutons. The source of the tin is unknown, and only 2 of 15 representative rock samples of the two plutons contain detectable amounts of tin.

Age

Available stratigraphic evidence suggests a probable Cretaceous age for the St. Lawrence plutons. The latest datable country rocks are of Triassic age, according to fossil evidence (Patton and Csejtey, 1971a). The age of the youngest intruded rocks, the andesitic volcanic rocks, is imperfectly known, but similar andesitic volcanic rocks in west-central Alaska have been dated as Early Cretaceous (Patton and Miller, 1966; Patton, 1967). The basal part of the oldest postplutonic rocks, a sequence of latitic and quartz latitic volcanics, yields a Late Cretaceous K-Ar age of 88.7±3 m.y. (million years) (Patton and Csejtey, 1971a).

Four K-Ar age determinations were obtained on three of the St. Lawrence plutons (table 2). Two ages were measured on biotite from the biotite quartz monzonite of the Sevuokuk pluton, one on biotite from the finer grained part of the biotite quartz monzonite of the Kialegak pluton, and one on hornblende from the monzonite-syenite member of the Kinipaghulghat pluton.

Three of the four ages are in close agreement, a little over 100 m.y. each, though they represent different members of the intrusive series. An age of 91 m.y. obtained on a sample from a mineralized satellitic stock of the Sevuokuk pluton (Patton and Csejtey, 1971a) probably reflects the effects of the postplutonic mineralization, or it may represent a younger plutonic episode. In any event, the small range of the measured ages suggests that the composite St. Lawrence plutons were emplaced in a relatively short period of geologic time, around 100 m.y. ago.

Regional correlation

Granitic plutons of similar age, composition, and structure occur in adjacent regions of Siberia and mainland Alaska.

A belt of epizonal granitic plutons has been described from west-central Alaska and from the eastern part of the Seward Peninsula by Miller (1970a). In the Seward Peninsula the plutons consist of quartz monzonite and lesser amounts of syenite and feldspathoidal rocks and have been assigned to a plutonic episode dated at 108–98 m.y. (Miller, 1971). In addition, the plutons in the Seward Peninsula trend approximately north-south and appear to be restricted to the boundary areas between the Precambrian and Paleozoic metamorphic and sedimentary rocks of the Seward Peninsula to the west, and the adjacent Mesozoic volcanogenic province to the east (Miller, 1970).

The country rocks on eastern St. Lawrence Island are dominantly Paleozoic carbonates, whereas those on the western part are chiefly Lower Cretaceous(?) andesitic volcanic rocks (fig. 2). Thus, on the basis of similar age, composition, and geologic setting, the plutons of St. Lawrence Island appear to be a continuation of the 100-m.y.-old plutonic belt of the eastern Seward Peninsula.

A broad belt of granitic plutons extends from the Siberian mainland into the Chukotsky Peninsula, U.S.S.R. (Shilo, 1965). The plutons are epizonal and composite, ranging in composition from quartz monzonite and granite to undersaturated syenite, and most are reportedly 80 to 100 m.y. old. In the southern half of the Chukotsky Peninsula the country rocks are mostly Mesozoic andesitic volcanic rocks, whereas in the northern half they consist mainly of Precambrian to Mesozoic metamorphic and sedimentary rocks (Drabkin, 1970). Thus, the geology and the geographic location of the St. Lawrence plutons strongly suggest a tectonic continuity, at least since the middle of the Cretaceous, across the Bering Sea shelf between the Chukotsky Peninsula and western Alaska.

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Table 2.—K-Ar *age determinations for granitic rocks of St. Lawrence Island, Alaska*

[Argon analyses and age calculations by J. C. Von Essen and J. Engels; potassium analyses by L. B. Schlocker]

Pluton and rock type	Map No. (figs. 5, 6)	Location		Field No.	Mineral	K_2O (percent)	Ar^{40}_{rad} (10^{-10} moles/g)	Ar^{40}_{rad} / Ar^{40}_{total}	Apparent age (millions of years)
		Lat (N.)	Long (W.)						
Sevuokuk; biotite quartz monzonite.	1	63°45′	171°40′	66AMm-211	Biotite	4.77, 4.72 (avg 4.745)	7.606	0.95	106±3
Sevuokuk; biotite quartz monzonite.	2	63°27′	171°32′	69APa-219e	. . . do . . .	7.94, 8.01 (avg 7.98)	.1102	.87	91.3±3
Kialegak; biotite quartz monzonite.	3	62°59′	169°35′	70ACy-162	. . . do . . .	8.17	.1257	.87	101±3
Kinipaghulghat; monzonite-syenite.	4	63°11′	168°25′	66AMm-245	Hornblende	1.48, 1.47 (avg 1.475)	2.277	.90	101.7±3.1

Decay constants for K^{40}: $\lambda_\epsilon = 0.585\times10^{-10}$ year^{-1}; $\lambda_\beta = 4.72\times10^{-10}$ year^{-1}. Atomic abundance of $K^{40} = 1.19\times10^{-4}$.

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GLACIATION OF THE RAY MOUNTAINS, CENTRAL ALASKA

By WARREN YEEND, Menlo Park, Calif.

Abstract.—The remote Ray Mountains in central Alaska show evidence of two late Pleistocene glaciations. Glaciers as much as 12 miles long occupied the valleys, draining the high, eastern part of the mountains. Remnants of lateral moraines indicate at least three stillstands of the ice during an early Wisconsin(?) glaciation. Hummocky moraines on the high mountain cirque floors were deposited by local cirque glaciers during the late Wisconsin. Evidence of pre-Wisconsin glaciation and Neoglaciation in the Ray Mountains was not found. Glaciers originating in the Ray Mountains in Wisconsin time stopped 28 miles short of the Yukon River and therefore could not have dammed the major drainage. Ice more or less equally distributed around the high parts of the mountains was most likely nourished by precipitation originating in the North Pacific Ocean and (or) Bering Sea.

The Ray Mountains in central Alaska, approximately 150 miles by air northwest of Fairbanks and 50 miles south of the Arctic Circle, remain one of the most inaccessible and least known regions of the continental United States. Except for the Alaskan hunter, an occasional prospector, or the U.S. Government topographer, probably only few people have reached the mountains. There are no roads or trails leading into the mountains, and consequently they are readily accessible only by light plane or helicopter.

The range is roughly 75 miles long and 20 miles wide and trends northwest by west. Although few peaks rise above 5,000 feet altitude, Mount Tozi, the highest point, reaches an altitude of 5,519 feet. The Yukon River forms the major drainage boundary southeast of the mountains, the Koyukuk River the drainage boundary northwest of the mountains (fig. 1).

Granitic intrusive rocks make up the bulk of the mountains; the surrounding metamorphic complex is dominated by gneissic hornfels, schists, quartzites, and greenstones.

In the summer of 1913, Henry M. Eakin (1916) led a U.S. Geological Survey field party of four by pack train on a geologic reconnaissance along the northern flank of the Ray Mountains. His report is the only early published account dealing with the geology of the region. Eakin recognized evidence of glaciation in the Ray Mountains and described moraines more than 20 miles down the valley from the main divides. He felt that ice may have extended "down the valleys considerably beyond the present outermost exposed moraines * * *."

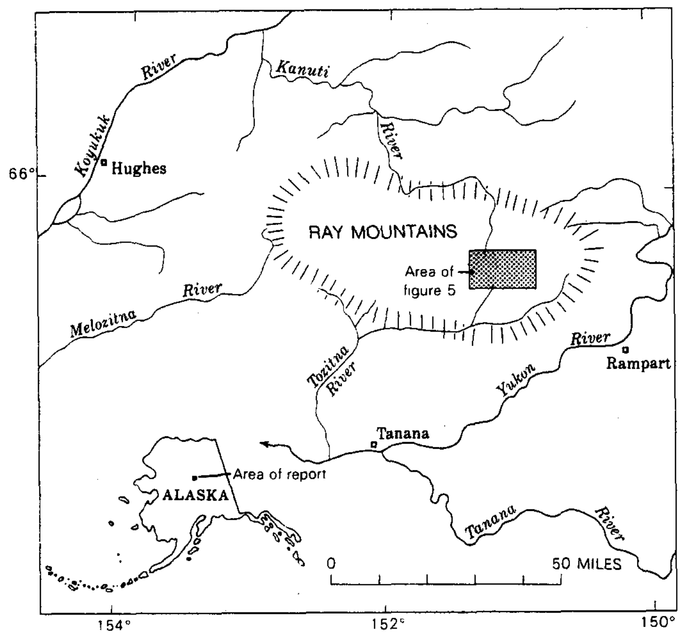

Figure 1.—Index map showing location of Ray Mountains, central Alaska.

Compilations of work in Alaska published in the 1960's and small-scale maps showing extent of glaciation and surficial deposits (Coulter and others, 1965; Karlstrom and others, 1964) show isolated-valley glacial deposits in the Ray Mountains.

Williams (1962, p. 323–324) suggested that glaciers originating in the Ray Mountains could have extended to the Yukon River and blocked its path, resulting in the impounding of water and the development of a large lake in the Yukon Flats, a large topographic depression through which the Yukon River flows east of, and upstream from, the Ray Mountains. A closer look at the extent of glaciation in the Ray Mountains seemed warranted. Part of the Ray Mountains were mapped with helicopter support in August and September 1970 as part of a project to map the Tanana 1:250,000 quadrangle, as well as to learn more about the regional geology in the vicinity of the proposed trans-Alaska pipeline.

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EVIDENCE OF GLACIATION

Erosive glacial features are common in the high parts of the Ray Mountains, providing the observer with the most conclusive evidence for the recognition of glaciation in the mountains. Depositional features such as moraines and outwash deposits are few, of small volume, and generally modified by postglacial solifluction processes. There are at present no active glaciers in the Ray Mountains.

Cirques, arêtes, and horns give the high parts of the mountains the classic rugged character typical of many glaciated mountain ranges. Of the approximately 25 well-developed cirques, almost all occur at altitudes of 3,500 and 3,700 feet, a few at 3,000 feet.

The broad, parabolic shape of the valley bottoms is the distinguishing feature of valleys that have been glaciated. The valley of Twilight Creek on the south side of the mountains and that of Halu Creek on the northeast side most markedly exhibit this characteristic profile. In the downstream parts of many of the glaciated valleys where terminal and lateral moraines are lacking, the change in valley profile from parabolic to more V-shaped is useful evidence of the maximum extent of ice in the valley.

Moraines are plentiful on the cirque floors, but small cirque lakes are rare. The moraines have no classic ice-bounding forms, but rather are irregular, low hummocky piles of unsorted till occupying the central part of the cirques (fig. 2). This till may represent the final ablation products of the ice subsequent to its withdrawal into the cirques. Ground moraine certainly present on the valley floors downvalley from the cirques has been modified and covered by subsequent active solifluction mantle. Only in several isolated localities is this ground moraine believed to exist unmodified. Two such areas are near the headwaters of the Kanuti Kilolitna and Big Salt Rivers.

Moraine forms marking the boundaries of ice tongues were identified in five separate valleys. Remnants of lateral moraines are preserved on the south side of the Halu Creek valley just upstream from the junction with the Big Salt River. Three separate low, smooth ridges of till less than 50 feet high extend transversely down the valley side to creek level and would seem to mark the termini of the ice tongue at closely spaced time intervals. The farthest downvalley moraine of the three is no more than 1 mile from the farthest upvalley moraine. A few granite and schist boulders as much as 6 feet in diameter are scattered on the moraine surface. The till, examined only in the upper 1 foot because of the ubiquitous permafrost, is composed largely of coarse sand and granules of granitic rocks with a clay matrix. As with most of the moraines observed, solifluction has disturbed the moraine surface producing streamlined slopes. The moraines are very smooth, lacking any hummocky forms.

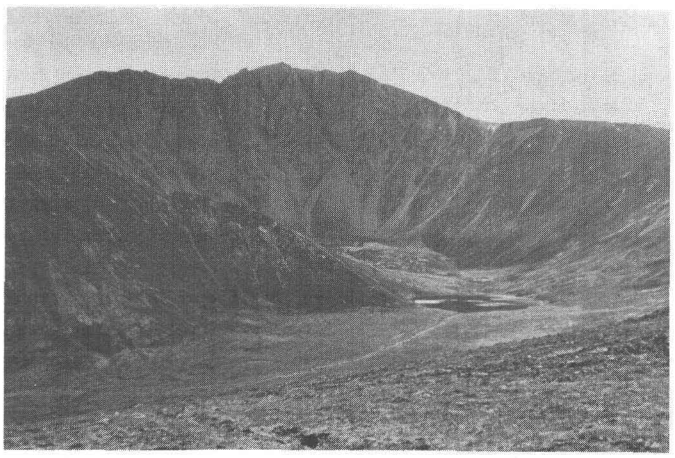


Figure 2.—Cirque at head of Kanuti Kilolitna River. Small lake is just downvalley from a late Wisconsin cirque moraine.

A single lateral moraine is present on the east side of the Twilight Creek valley, beginning about 3 miles upstream from the junction with the Tozitna River (fig. 3). The surface of the moraine is 500–600 feet above the valley floor and would seem to indicate ice of at least that thickness in the valley during glaciation of the mountains. At least three levels of glacial drift seem to be represented beneath the active solifluction mantle on the west side of the Twilight Creek valley. Whether these are kame terraces or moraines is difficult to determine because of the cover.

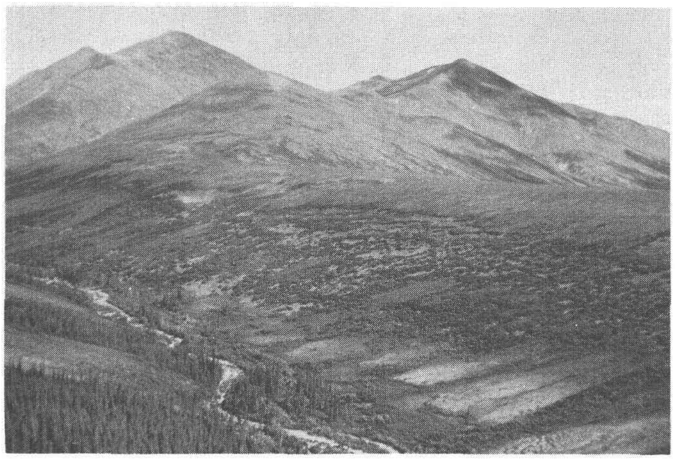


Figure 3.—Valley of Twilight Creek, showing lateral moraine (even, gentle slope in right foreground) left by glaciers of early Wisconsin(?) age. Mount Tozi, highest peak in the Ray Mountains, is the high peak on left. View northeast.

Unsorted till 150–200 feet thick is present on the divide between Crash Creek and the Big Salt River. Extending north from this locality into the drainage of the Big Salt River is a low ridge that separates two headwater tributaries of the Big Salt. This feature could be interpreted as a medial moraine.

Remnants of a terminal and a recessional moraine are present in a northwestward-flowing unnamed tributary of the Kanuti Kilolitna River. A small lake is held in by the low terminal moraine. These moraines are less than 30 feet high and have bouldery surfaces.

By far the best developed moraine complex is a recessional moraine near the head of the Kanuti Kilolitna River (fig. 4) that curves across the valley, indicating quite vividly the position of the ice front. The moraine is hummocky, having relief of about 40 feet, and has been breached by the Kanuti Kilolitna River near its center.

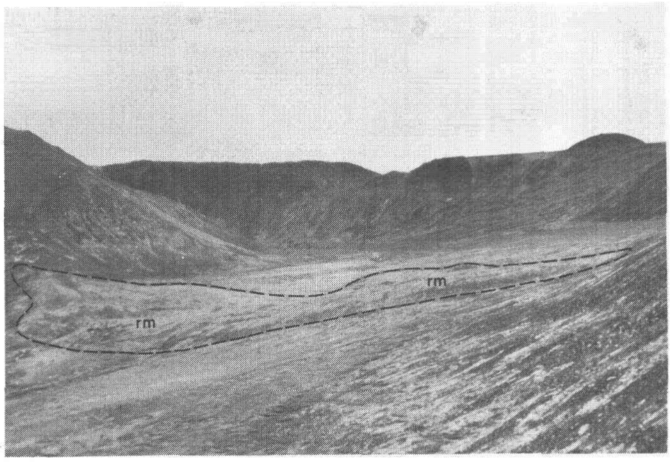


Figure 4.—Early Wisconsin(?) recessional moraine (rm) near the headwaters of the Kanuti Kilolitna River. Moraine has been breached by the river in left foreground. View southwest.

ICE EXTENT

The maximum extent of glaciers that occupied the Ray Mountains, interpreted on the basis of erosive and depositional features, is shown in figure 5. Ice accumulated in the eastern, highest part of the mountains to a sufficient thickness to flow down the major drainages, and, in some places, overwhelm low divides between drainages. Much of the mountain range shows no effects of glaciation. A local isolated ice buildup occurred at the headwaters of the Kanuti Kilolitna River on the north-facing slopes of the mountains. It appears that much of the Ray Mountains was below the critical altitude necessary for large ice accumulation, and therefore only those highlands with substantial accumulation area above 3,500 feet were glaciated.

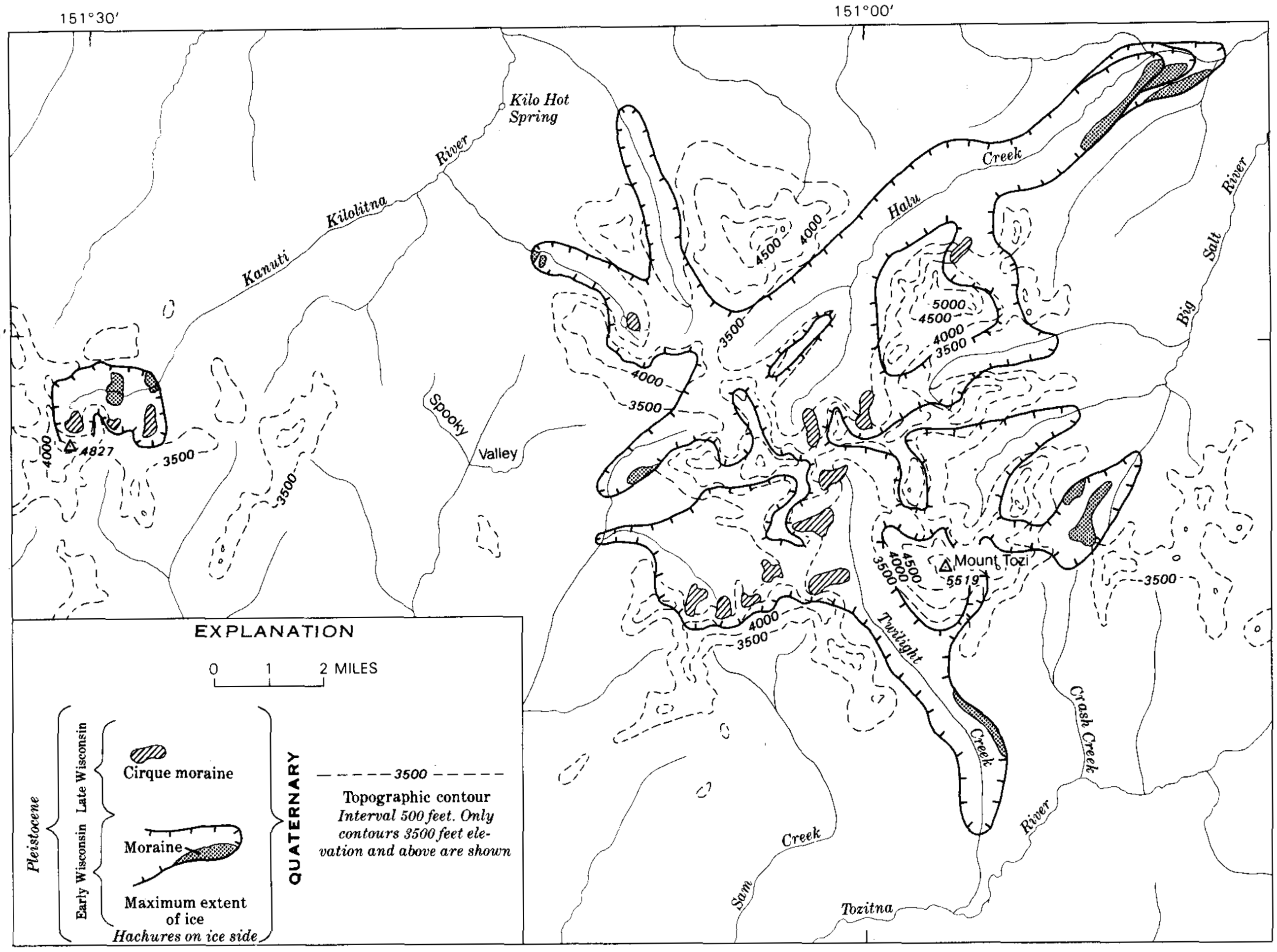
Two major ice tongues occupied the Halu and Twilight Creek valleys. Ice in the Halu Creek valley, on the northeast side of the mountains, reached a length of 12 miles, the longest ice tongue in the mountains. This glacier may have been as much as 800 feet thick. The ice tongue in the Twilight Creek valley, on the south side of the mountains, was 8 miles long and may have averaged 500–600 feet in thickness. Ice was able to flow farther down these drainages than others because the accumulation areas feeding ice into these drainages were extensive. Ice did not extend an appreciable distance down either the Big Salt River or Crash Creek because the snow-accumulating zone on the northeast side of Mount Tozi was small. A similar situation existed at the headwaters of the Kanuti Kilolitna River, where the snow-accumulating area above 3,500 feet is relatively small. Ice flowed less than 2 miles down this drainage.

It seems clear that glaciers from the Ray Mountains did not approach the vicinity of the Yukon River and, therefore, could not have been instrumental in damming this major drainage. The long glacier that flowed down Halu Creek stopped 28 miles short of the Yukon River. If ice from the Ray Mountains did at one time extend to the vicinity of the Yukon River, all evidence of it has vanished.

The location of source areas for the precipitation that resulted in the glaciation of the Ray Mountains is speculative. The logical source areas would have been either the Arctic Ocean to the north, assuming that the Arctic Ocean was ice free (Ewing and Donn, 1963), or the northern Pacific Ocean and Bering Sea to the south and southwest. Had glaciers been nourished by air masses from the north, it is unlikely, considering the greater insolation on the south-facing slopes and the precipitation "shadow" effect, that there would have been much ice buildup on these slopes. And, as figure 5 shows, there was not. Except for the local ice mass that existed near the head of the Kanuti Kilolitna River, glaciers were distributed fairly evenly around the high parts of the Ray Mountains. It seems clear that only with a supply of moisture from the south and (or) southwest could ice have built up on the south-facing slopes. Evidently the heavy snowfall on the south slopes more than offset the effect of insolation. In those areas where the accumulation zone was lower and of smaller area, such as at the headwaters of the Kanuti Kilolitna River, only on the protected north slopes was ice able to build up sufficiently to initiate glaciation, and the effects of insolation on the south-facing slopes overcame those contributing to greater accumulation. A similar North Pacific source area for late Quaternary glaciation in Alaska has been suggested by Péwé and others (1965).

MULTIPLE GLACIATION

Two major periods of glaciation seem evident within the Ray Mountains. The first, more widespread phase is characterized by the broad U-shaped valleys that contained glaciers 12 miles long. The second phase, which may in fact represent nothing more than the withdrawal of ice from the earlier phase, was marked by the presence of cirque glaciers only. This glacial event, restricted to the cirques, would seem to be the youngest, primarily on the basis of the fresh unmodified form of the moraines and complete lack of soil development. The more extensive older glaciation was characterized by at least three minor stillstands of the ice as shown by the three nested moraines in Halu Creek and the three drift levels along the south side of Twilight Creek. The moraines in Halu Creek have only a hint of soil development—a faint colored B horizon, 0.3



Base from U.S. Geological Survey 1:250,000, Tanana, 1956

Figure 5.—Map of the eastern, highest part of the Ray Mountains, showing maximum extent of glaciation. See figure 1 for location of map area.

feet thick. The B horizon is dark grayish brown, 2.5*Y* 4/2, as determined from the Munsell soil-color charts. The underlying clayey till is olive gray, 5*Y* 4/2. A textural change is not apparent. Soils on the few glacial deposits of this older phase, determined to be unaffected by postglacial solifluction, are developed very poorly or not at all. On the basis of the morphology of deposits, weak soil development, and extent of ice, the older glaciation in the Ray Mountains is questionably correlated with the Kobuk Glaciation of possible early Wisconsin age, identified in the Alatna Valley of the Brooks Range (Hamilton, 1969).

The younger glacial event is correlated with the late Wisconsin Itkillik Glaciation of the Alatna Valley (Hamilton, 1969). This tenuous correlation is based on the fresh, hummocky moraines lacking soil development. It is thought that the Ray Mountains escaped the effects of Neoglaciation because of their low altitude and small areal extent. An alternative hypothesis is that the cirque glaciation is, in fact, a neoglacial event and the more extensive glaciation of both early and late Wisconsin age.

At least two alpine glaciations are identified in the Yukon-Tanana upland 100–200 miles southeast of the Ray Mountains (Péwé and others, 1967). They have been considered Wisconsin and pre-Wisconsin in age.

CONCLUSIONS

The Ray Mountains were occupied by glaciers during Wisconsin time. Ice tongues as much as 12 miles long were present in the mountain valleys during early Wisconsin time but had withdrawn to the cirques by late Wisconsin time. Glaciers originating in the Ray Mountains in Wisconsin time did not extend to the Yukon River and therefore could not have dammed the major drainage. The North Pacific Ocean and (or) the Bering Sea most likely provided the precipitation resulting in the Wisconsin glaciations of the Ray Mountains.

Evidence for pre-Wisconsin glaciation in the Ray Mountains was not found.

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RECONNAISSANCE OF GROUND-WATER SUPPLIES FROM BEDROCK IN THE METLAKATLA PENINSULA, ANNETTE ISLAND, ALASKA

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Work done in cooperation with the Federal Aviation Administration

Abstract.—Bedrock in the western part of Annette Island, herein referred to as the Metlakatla peninsula, consists of igneous and metamorphic rocks that yield water only from fractures. A test well, 362 feet deep, obtained water between 305 and 362 feet. Initial production of the well was 100 gpm (gallons per minute), but results from a 12-hour recovery test suggested that this rate probably could not be maintained because of hydrologic boundaries. When the well was pumped continuously at a rate of 35 gpm for more than 3 months, the water level declined 125 feet at an average rate of 0.6 foot per day to about 115 feet below sea level. Chemical analyses show that ground water is a sodium bicarbonate type. During pumping of the test well, the chloride content of the water increased from 75 to 222 mg/l (milligrams per liter) indicating that salt water was entering the aquifer.

Although annual precipitation in southeastern Alaska is as much as 269 inches, the igneous and metamorphic rocks underlying most of the region generally yield only small amounts of water. This report describes the results of a project to develop ground-water supplies from bedrock on Annette Island. Some of the conclusions derived from the project are applicable to other areas because the climate, topography, and geology of the island are typical of much of southeastern Alaska.

As a major part of the project, five small-diameter holes were drilled to determine the subsurface distribution of fracture zones and, where possible, to test the water-yielding capabilities of each zone. Drill hole 5 had the greatest potential as a source of water and, therefore, was redrilled as a test well. Each water-bearing zone in this well was tested for yield, a water sample collected for chemical analysis, and, upon completion of drilling, a 12-hour recovery test was made.

Interbedded gravel, sand, silt, and clay interpreted as raised beach deposits, which may be potential sources of ground water, were studied in some detail and are described more fully in a companion paper (Marcher, 1971) (p. D202–D205, this chapter).

GENERAL SETTING

Annette Island is in extreme southeastern Alaska (fig. 1). The western part of the island, an area of about 20 square miles herein referred to as the Metlakatla peninsula, is mostly a swampy, heavily vegetated lowland generally less than 200 feet above sea level.

Annette Island lies in the Wrangell-Revillagigedo belt of metamorphic rocks (Buddington and Chapin, 1929, p. 181–183). Mapping by Berg (1969) shows that bedrock in the Metlakatla peninsula is chiefly schist, gneiss, and hornfels. These rocks are locally mixed and in part gradational with, foliated granitic rocks, which, in turn, grade into foliated quartz diorite and diorite. An area of about 1.5 square miles in the vicinity of Yellow Hill is underlain by dunite and pyroxenite. Sedimentary rocks include muck, glacial till, and raised beach deposits.

GROUND WATER IN BEDROCK

Bedrock fractures

The number, spacing, attitude, size, and interconnection of fractures such as joints and faults control the occurrence, storage, and movement of ground water in bedrock in the Metlakatla peninsula. Observations, mainly along the beach, showed a wide variety in the degree and type of jointing. For example, in some areas three sets of uniform, well-developed joints in coarse-grained dioritic rocks intersect to produce sharply defined trihedral blocks. Elsewhere, similar rocks are rather thoroughly fractured but the fractures do not follow any discernible pattern. Measurements showed that the major sets of joints strike between N. 15° E. and N. 15° W. Other sets strike N. 25°–35° E. and N. 55°–65° W. Of 63 measurements of joint dips, about 47 percent dip at angles greater than 80°, and nearly 95 percent dip at angles greater than 45°.

A 23-foot drill core taken from drill hole 4 from a depth of

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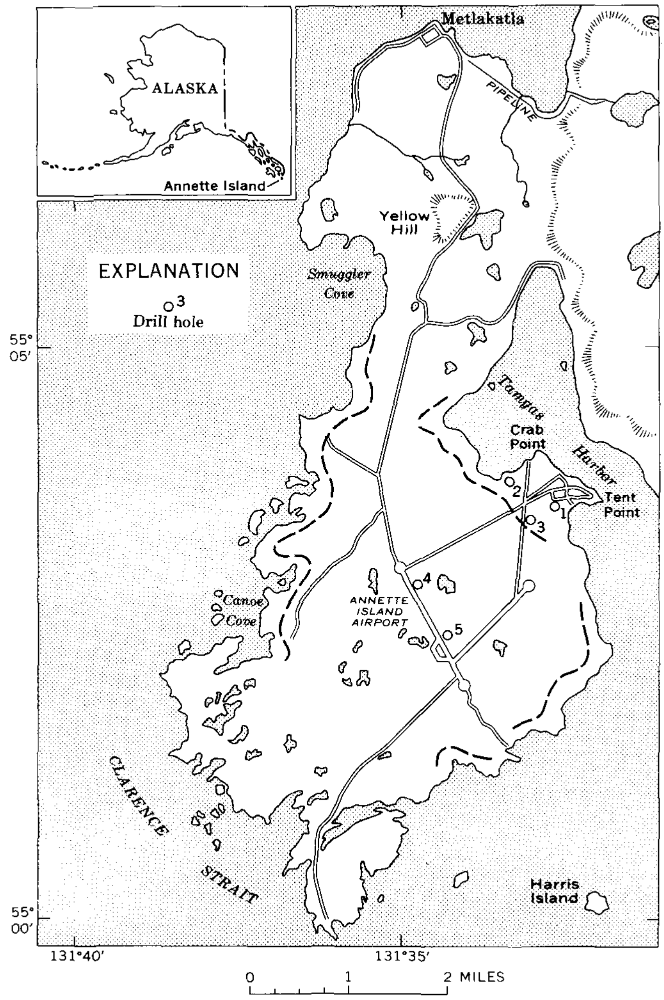

Figure 1.—Map of Metlakatla peninsula, Annette Island, Alaska, showing location of drill holes.

47–70 feet provided information on shallow subsurface joints. This core showed about 70 joints for an average of about three per foot. The width of these joints ranges from a hairline to about one-sixteenth inch, and many were partly or completely healed with quartz. Where the fractures were not fairly well healed, the core broke and the width of the fractures could not be determined. Because most of the fractures had been healed or were very narrow, the test hole did not yield a significant amount of water.

Highly fractured ultrabasic rocks south of Yellow Hill provide openings for seeps and small springs. Other small seeps issue from fractured rocks along the west side of the peninsula; these seeps undoubtedly go dry in the summer.

Rocks penetrated in the interval above 305 feet in the test well were nearly free of fractures, but zones of fractured rock were indicated below this depth by the difficulty experienced in maintaining a straight and round hole. Furthermore, the increase in well yield and reduction in drawdown described in the summary of test pumping suggest that the abundance of fractures increases with depth. The interval between 305 and 362 feet in the test well is interpreted as a fault zone because normally the number of fractures decreases with depth. Even though a fault zone may yield the major supply of ground water to the well, most recharge to the faults probably takes place through overlying jointed rock.

Test drilling and pumping

Results of test drilling and yield tests are summarized as follows:

Drill hole 1 reached a total depth of 295 feet and was abandoned because brackish water was obtained at that depth. A water-bearing zone, between 86 and 126 feet, was tested by pumping with air for 12 hours at a rate of one third gpm (gallon per minute).

Drill hole 2 reached a total depth of 113 feet. A water-bearing zone between 94 and 96 feet was tested by pumping with air at a rate of one-half gpm that increased to 1 gpm after 30 hours.

Drill hole 3 reached a total depth of 215 feet. A water-bearing zone between 92 and 95 feet was pumped with air at a rate of two-thirds gpm for 4 hours but did not increase in yield.

Drill hole 4 reached a depth of 104 feet, but no water was obtained.

Drill hole 5 was drilled using a core drill to a depth of 305 feet. The hole was then redrilled for a test well to a depth of 362 feet using a 6-inch churn drill. The results of testing the various water-bearing zones in this well are summarized below.

Depth (feet)	*Summary of testing*
70– 90	Pumped with air ½ gpm for 8 hours. Cemented in after pumping.
109–121	Pumped with air 2/3 gpm for 8 hours. Cemented in after pumping.
183–209	Pumped with air 2/3 gpm for 8 hours. Cemented in after pumping.
272–282	Pumped with air 1 2/3 gpm for 8 hours. Cemented in after pumping.
297–305	Pumped with air 8 gpm for 24 hours.
305–313	Pumped with air 12½ gpm for 16 hours with 130 feet drawdown. Static level 10 feet.
313–320	Pumped 16 hours at 30 gpm with 94 feet of drawdown. Static level 13 feet.
321–326	Pumped 72 hours at 37 gpm with drawdown of 80 feet. Static level 23 feet.
332–336	Pumped 23 hours at 37 gpm with drawdown of 67 feet. Static level 23 feet.

Fresh ground water beneath Annette Island is in contact with sea water. Excessive lowering of the water table in a pumping well may cause salt water to enter and contaminate the aquifer. To forestall such a possibility, drawdown in the well must be carefully controlled.

To estimate the amount of drawdown after pumping the production well for an extended period of time and to estimate the long-term yield, a 12-hour recovery test was run. Analysis of the test data indicates that impermeable boundaries are present in the vicinity of the well and that the initial yield of 100 gpm could not be maintained without excessive drawdown.

Subsequent to the recovery test a pump was installed in the well and operated almost continuously at a rate of 35 gpm for more than 3 months. Water-level measurements made during this period, plotted against time, are shown in figure 2. Examination of the drawdown curve shows that from a level of 127 feet shortly after pumping started, the water level declined to 206 feet after 100 days of pumping. Total drawdown from static level was 125 feet.

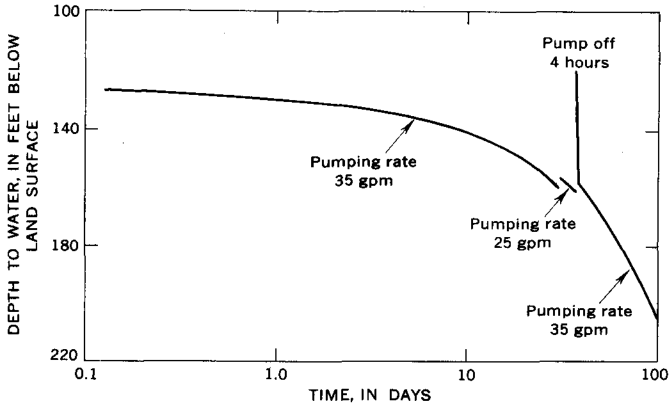

Figure 2.—Drawdown in the test well after pumping 100 days. Water level at start of pumping was 81 feet.

During the 3-month pumping period, the rate of drawdown was far in excess of that estimated on the basis of the test. Apparently the water-yielding zones are separated from one another and from surface recharge by considerable thicknesses of unfractured rock so that when they are drained of their stored water, replenishment takes place slowly. Hydrologic boundaries undoubtedly are present, because the fracture zones are not continuous and because the degree of fracturing along individual zones differs from place to place.

Chemical quality

At least one sample of water for chemical analysis was collected from each drill hole except number 4, and samples from four of the water-bearing zones in the test well were analyzed to determine variations in chemical quality with depth. Several samples were collected from the completed well after different periods of pumping and analyzed to determine changes in chemical quality that would indicate salt-water intrusion. The results of the analyses are given in table 1.

By plotting the results of the chemical analyses according to a method devised by Stiff (1951, p. 15–16), the gross chemical characteristics of the water can be compared as shown in figure 3.

Table 1.—*Chemical analyses of ground water from Metlakatla peninsula, Annette Island, Alaska*

[All analyses made by U.S. Geological Survey. Results in milligrams per liter except where indicated]

Source of water	Date of collection	Silica (SiO_2)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)
Drill hole 1	7-29-64	2.7	0.43	12	14	720	2.2	471	24	327	642
2	8- 8-64	7.7	.60	6.4	.5	220	.8	551	12	7.2	9.2
3	9- 1-64	20	.40	12	1.2	200	.3	558	0	4.8	5.7
5	9-13-64	31	.73	7.2	3.2	89	1.7	235	4	6.1	12
	9-21-64	25	.27	1.6	1.9	105	1.0	215	12	7.2	14
	9-28-64	15	.25	1.6	2.4	193	6.7	404	11	3.8	24
	10- 2-64	15	.04	.8	1.9	200	.6	451	17	4.3	42
Test well	5-26-65	17	.29	.0	7.1	235	8.5	493	30	6.7	74
	7- 7-65	18	.02	.0	4.4	276	9.2	480	22	25	125
	8-10-65	17	.00	.0	3.9	300	9.0	487	19	16	155
	8-26-65	16	.2	4	2.6	300	8.8	502	18	23	172

Source of water	Date of collection	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (calculated)	Hardness as $CaCO_3$	Specific conductance (micromhos) at 25°C	pH (pH units)	Color (Pt-Co scale units)	Remarks
Drill hole 1	7-29-64	1.2	0.2	1,970	86	3,260	8.4	45	Water from 86–126-foot zone.
2	8- 8-64	1.1	.3	337	18	859	8.3	50	Water from 94–96-foot zone.
3	9- 1-64	.1	.8	520	35	830	8.2	30	Water from 92–95-foot zone.
5	9-13-64	.1	.6	260	31	434	8.4	30	Water from 109–121-foot zone.
	9-21-64	.1	1.2	287	12	449	9.0	10	Water from 183–209-foot zone.
	9-28-64	.2	1.0	463	14	758	9.0	10	Water from 272–282-foot zone.
	10- 2-64	.2	.9	506	10	859	9.0	10	Water from 297–305-foot zone.
Test well	5-26-65	.2	.3	592	29	958	8.9	12	After pumping 72 hours.
	7- 7-65	.2	.2	705	18	1,190	8.7	5	After pumping 730 hours.
	8-10-65	.3	.1	750	16	1,290	8.7	5	After pumping about 1,550 hours.
	8-25-65	.2	.1	782	21	1,355	8.6	10	After pumping about 1,900 hours.

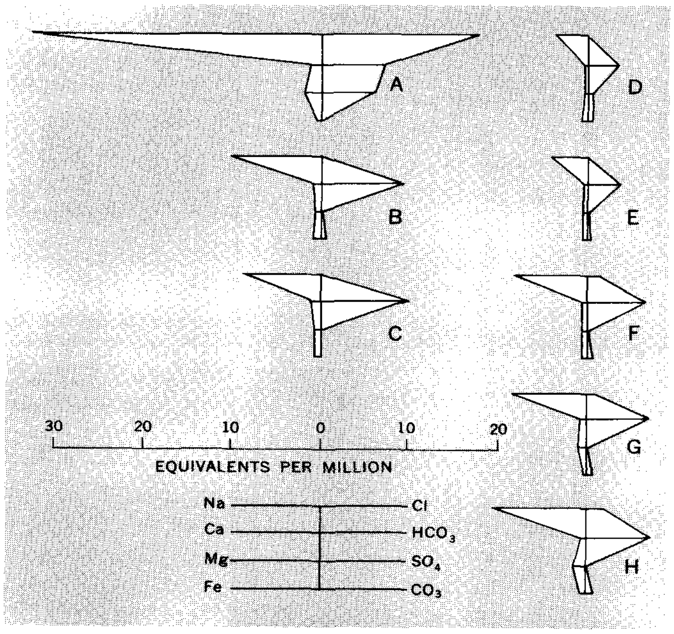

Figure 3.—Chemical characteristics of ground water from Metlakatla peninsula. A, drill hole 1; B, drill hole 2; C, drill hole 3; D, drill hole 5, 109–121 feet; E, drill hole 5, 183–209 feet; F, drill hole 5, 272–282 feet; G, drill hole 5, 297–305 feet; H, test well, composite of all producing zones.

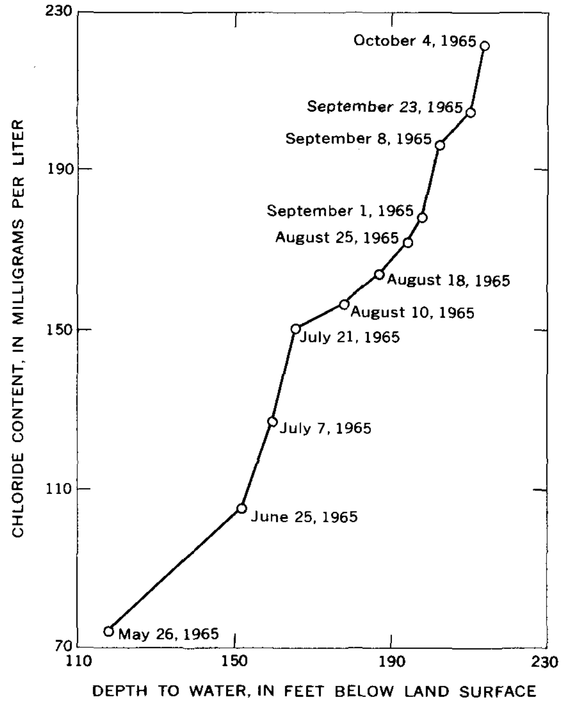

Figure 4.—Increase of chloride content of water in test well with increasing drawdown.

Samples from drill holes 2 and 3 and the composite sample from the test well show that the water is a sodium bicarbonate type.

The high sodium, magnesium, sulfate, and chloride contents in water from drill hole 1 suggest admixture of sea water with normal ground water.

During drilling of the test well, samples were collected from water-bearing zones at depths of 109–121, 183–209, 272–282, and 297–305 feet. These samples were collected after the hole had been pumped to remove all drilling fluids, thereby assuring a representative water sample. After each sample was collected, the water-bearing zone was sealed with cement and drilling continued. Thus, each sample from above 305 feet represents water from a single fracture zone. Samples from below a depth of 305 feet are a composite of all water-bearing zones penetrated by the well.

Chemical analyses show that the concentration of some constituents changed little with depth (table 1). Other constituents, particularly sodium and bicarbonate, increased rather markedly with depth. These increases are presumably the result of the water being in contact with the rock longer as it slowly moves downward or incomplete flushing of sea water from deeper crevices.

Because of the potential hazard of salt-water intrusion with progressive lowering of the water level in the test well during pumping, samples were collected intermittently between April and October 1965 and tested for chloride content. Figure 4 shows that the average chloride content increase was about 15 mg/l for every 10 feet of drawdown.

CONCLUSIONS

Four out of five drill holes produced small amounts of water from bedrock in the Metlakatla peninsula; geologically similar terranes in southeastern Alaska also might be expected to provide small supplies. Fractured zones at depths of less than 150 feet are more likely to provide a continuing supply of water because recharge can take place more rapidly. Although the test well drilled during this study cannot be pumped continuously at a rate of 35 gpm, it will provide that amount intermittently. However, drawdown must be carefully controlled to prevent encroachment of salt water. Additional supplies may be available from fracture zones, which can be located only by test drilling.

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RAISED BEACH DEPOSITS AND THEIR GROUND-WATER POTENTIAL IN THE SOUTHERN PART OF THE METLAKATLA PENINSULA, ANNETTE ISLAND, ALASKA

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Work done in cooperation with the Federal Aviation Administration

Abstract.—Interbedded layers of gravel and sand on the Metlakatla peninsula are interpreted as raised beach deposits derived largely from marine, glaciomarine, and glacial deposits reworked by waves and tidal currents. Such deposits and similar deposits elsewhere in southeastern Alaska may be potential sources of small ground-water supplies.

Ground-water supplies in bedrock of southeastern Alaska, which are described in a companion paper (Marcher, 1971) (p. D198–D201, this chapter), may be difficult and costly to locate. Thus, in some parts of the region the search for ground water is most logically directed toward locating alluvial or similar deposits sufficiently thick and permeable to store and yield water. Layers of gravel and sand that make up ancient beach deposits in some areas may be potential sources of water. These deposits are also potential sources of aggregate materials in a region where bedrock is almost everywhere at or near the surface.

As part of a project to locate water supplies on the Metlakatla peninsula, the raised beach deposits were studied briefly. Drill holes, scattered surface exposures, and excavations near Crab Point provide information on the thickness, stratigraphy, and general lithology of the deposits. Size analyses of surface samples and differential thermal analysis of a clay sample were made in the laboratories of the U.S. Geological Survey, Denver, Colo.

DISTRIBUTION AND THICKNESS

In regard to the inferred distribution of the raised beach deposits, L. A. Yehle reports (written commun., Nov. 1970) as follows:

> * * * a 1:20,000 scale topographic map of the southern part of Metlakatla peninsula prepared in 1940 by the U.S. Geological Survey * * * shows several levels of benches or terraces * * *. Altitudinally, the lowest cluster of levels is up to about 30 to 35 feet above msl (mean sea level) and many others have their inner margin about 25 feet above msl. An intermediate cluster of bench or terrace levels is between about 50 and 55 feet above msl. A much less well developed, and higher, cluster of levels is between about 95 and 110 feet above msl. Between all these clusters of levels there are other scattered benches or terraces.

Yehle also notes (written commun., Nov. 1970) as follows:

> At Metlakatla town, Dick Lemke and I noted sand and gravel underlying the ground surface up to an altitude of at least 50 feet above mean sea level. These (presumably) wave and tidal current-worked materials well may extend to slightly higher altitudes. In the central part of town there is a hint of a very minor break-in slope at about 35 feet above msl. In the western part of town this altitude is at the lower margin of a more prominent break-in slope. However, in the latter area, no data on materials are available.

Drill-hole records and scattered outcrops along streams in the southern part of the peninsula show that at least some of the benches noted by Yehle are underlain by raised beach deposits. The highest known raised beach deposits underlie a terrace at the 50-foot level at the site of drill hole 3. The deposits are absent at higher levels in at least part of the area as shown by the logs of drill holes 4 and 5 (95 and 115 feet above sea level, respectively); both drill holes passed directly from muck into bedrock.

Drill-hole logs (table 1) show that raised beach deposits are as much as 5 feet thick. Exposures near the modern beach and in stream banks near the narrow part of the peninsula show that the deposits are at least 10–12 feet thick in this part of the area. Similar thicknesses were seen in construction excavations near Tent and Crab Points and in nearby surface outcrops.

LITHOLOGY

Drill-hole logs and surface exposures show the general lithology and stratigraphy of the raised beach deposits and indicate that lateral changes in lithology take place over short

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Table 1.—*Driller's logs of drill holes penetrating raised beach deposits*

[Logs provided by A. J. Lappi, Federal Aviation Administration]

	Thickness (feet)	Depth (feet)
Drill hole 1—Altitude 10 feet (altimeter)		
Rock fill	3	0– 3
Muskeg and muck	4	3– 7
Brown gravel and sand, some silty clay (some water).	4	7–11
Granite	..	11
Drill hole 2—Altitude 15 feet (altimeter)		
Rock fill	1	1– 2
Muskeg and muck (some water)	3	2– 5
Sand (some water)	1	5– 6
Sand and gravel (some water)	4	6–10
Blue silty clay and some gravel (some water). Fragments of clams, snails, and barnacles.	5	10–15
Gravel with white clay (some water)	4	15–19
White clay mixed with gravel (no water)	5	19–24
Brown clay mixed with gravel	5	24–29
Brown clay	4	29–33
Granite	4	33
Drill hole 3—Altitude 50 feet (altimeter)		
Rock fill	2	0– 2
Muskeg and muck (some water)	6	2– 8
Gravel (some water)	1	8– 9
Blue silty clay	1	9–10
Blue silty clay mixed with gravel	3	10–13
Hardpan mixed with gravel	8	13–21
Clay and some gravel	3	21–24
Hardpan mixed with gravel (some water)	4	24–28
Granite	..	28

distances. At locality 21-5 (fig. 1) raised beach deposits, about 10 feet thick, exposed about 40 feet above tide level, consist mainly of interbedded layers and lenses of gravel, sand, silt, and clay containing cobbles up to 8 inches in diameter. Visual estimation indicates that about two-thirds of the gravel and cobbles are subangular and about one-third are subrounded to rounded. The upper 2 feet of the exposure is heavily stained by iron oxide and organic matter; within this interval a few layers less than 1 inch thick are weakly cemented by iron oxide. Size analysis of a grab sample from this locality shows that about 50 percent of the sample is larger than 4 mm (millimeters) in diameter (fig. 2). The particle-size distribution curve (fig. 2) shows that sorting is poor.

At locality 35-1 the raised beach deposits consist of 4–6 feet of sandy gravel overlying silty and clayey bluish-gray sand of unknown thickness. Analysis of a sample (35-1A) from the gravel shows that sorting is poor and that about 55 percent of the sample is larger than 4 mm; the median particle size is between 5 and 6 mm. The larger particles are subangular to well rounded; perhaps 30–50 percent subangular. Analysis of a sand sample (35-1B) from this locality shows that the sand has a sorting coefficient of 1.7, indicating that it is well sorted. About 50 percent of the sample is in the fine and very fine size range; the medium size is 0.075 mm.

The stratigraphic sequence at locality 36-1 consists of an unknown thickness of bluish-gray clay overlain by about 6 feet

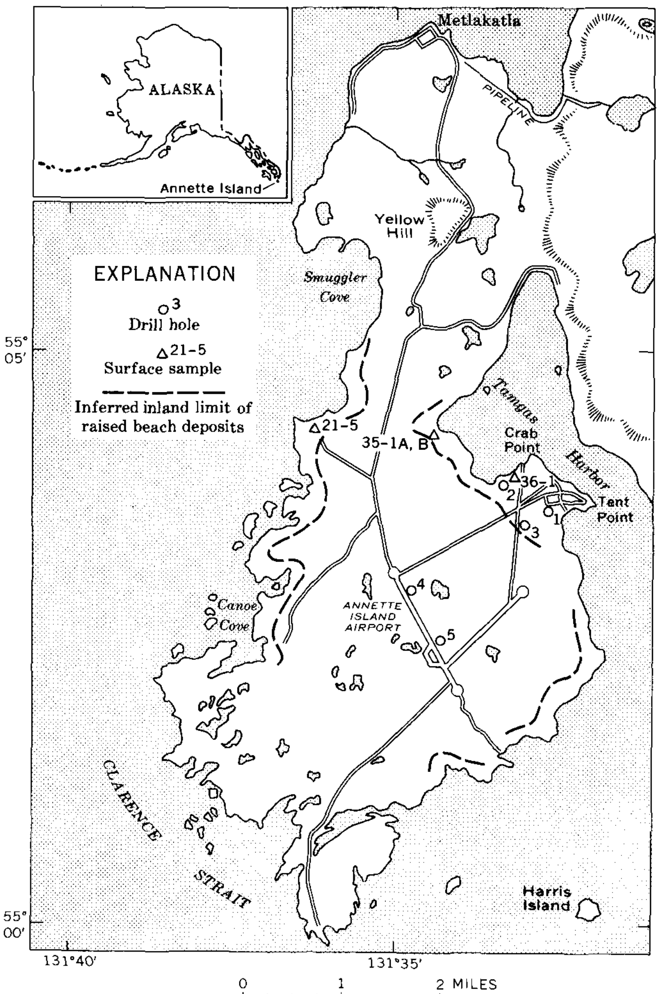

Figure 1.—Map of the Metlakatla peninsula, showing location of drill holes and surface samples, and inferred limit of raised beach deposits.

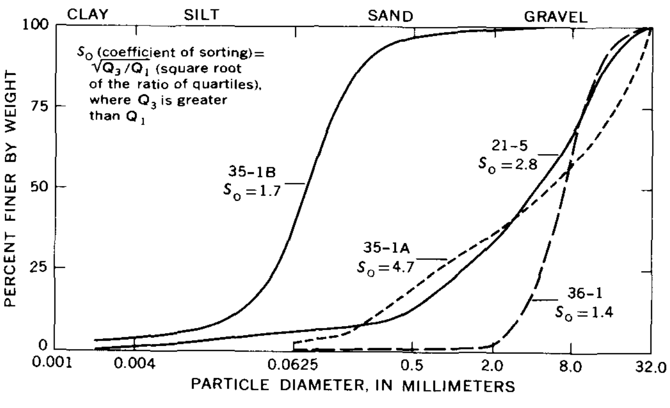

Figure 2.—Particle-size distribution of surface samples from raised beach deposits. See figure 1 for sample localities.

of gravel which, in turn, is overlain by about 4 feet of organically rich muck. Near the middle of the gravel layer is a wedge of silty peat containing fragments of partly lignitized wood as much as 2 feet long. The gravel at this locality, in contrast to that of the other localities, is well sorted, as shown by a sorting coefficient of 1.4, and most of the particles are subrounded to well rounded. About 80 percent of the sample is larger than 4 mm, and the mediun size is about 7 mm.

Differential thermal analysis of a clay sample from locality 36-1 shows that the clay is illite, a common constituent of both marine and glacial deposits (Grim, 1955, p. 484).

ORIGIN

The origin of the deposits herein referred to as raised beaches is reflected in their beltlike pattern of distribution and stratigraphy. Based on Chapin's suggestion (1918, p. 99) that the Metlakatla peninsula is a wave-cut bench, raised beach deposits are logically expected in this area. A more complex origin was postulated by Buddington (1927, p. 51) who suggested that the peninsula is largely the product of subaerial erosion and glaciation subsequently modified by marine erosion between successive uplifts. Periods of stable sea level would allow time for the accumulation of beach deposits, and uplift would preserve such deposits by removing them from the zone of wave erosion.

At least part of the raised beach deposits is derived by wave and tidal current erosion of marine or glaciomarine deposits. Indication of marine origin is provided by fossils, such as fragments of clams, snails, and barnacles in samples of silty clay from drill hole 2 at a depth of 11–14 feet. However, the clay contained no microfossils. Similar silty clay was penetrated in drill holes 1 and 3, but no samples were collected, hence, the presence or absence of fossils in the deposits at these sites is not known.

Modern beach deposits on the Metlakatla peninsula appear to consist of both locally derived and exotic fragments. The older raised beach deposits, however, apparently consist of material derived mainly from glaciomarine and glacial deposits that have been reworked by wave and tidal current action. Modern beach gravel on Prince of Wales Island has been described by Sainsbury (1961, p. 332) who points out that the gravel is rounded and unstriated and that most of the rock-flour matrix has been removed. Sainsbury further states that typical glacial deposits could probably be found at shallow depth beneath many of the beaches. Material described in the logs of drill holes in Metlakatla peninsula suggests glacial material such as the hardpan noted in drill hole 3. However, no striated or faceted rock particles were recovered during test drilling nor were any noted in surface outcrops.

Information on uplift required to elevate the raised beach deposits above the zone of wave erosion, thus preserving them, is provided by Twenhofel (1952, p. 523–548) who reviewed and summarized the literature relating to shoreline changes along the Pacific coast of Alaska. Most of his evidence for uplift is based on fossil-bearing marine deposits, commonly derived from glacial and glaciomarine material and very similar to those in the Metlakatla peninsula. Twenhofel describes deposits that have been elevated from a few to several hundred feet above sea level and cites evidence obtained by previous workers to show that uplift has amounted to 500 feet or perhaps more in the Portland Canal and Juneau areas.

Hicks and Shofnos (1965, p. 3315–3320) present sea-level data to show that nearly all southeastern Alaska is rising. The center of uplift is in the vicinity of Glacier Bay about 320 miles north of Annette Island. At Ketchikan, only 15 miles north of Annette Island, uplift amounts to about 3 centimeters per century. Uplift on nearby Gravina Island has been as much as 80 feet as shown by marine fossils in blue clay and gravel at that altitude (Chapin, 1918, p. 99). Uplift can take place suddenly and dramatically as shown by more than 7 feet of uplift associated with the Alaskan earthquake of March 27, 1964 (Grantz and others, 1964, p. 4).

WATER-SUPPLY POTENTIAL

With average precipitation of 117 inches fairly well distributed throughout the year, the raised beach deposits on Metlakatla peninsula should receive nearly continuous recharge. However, the several feet of overlying muck are poorly permeable; thus the rate of recharge may be rather slow.

During an extended dry period the beach deposits at higher altitudes would drain first. Therefore, the most favorable sites for ground water from these deposits are in low areas but above the tidal range to eliminate the danger of contamination by salt water. Infiltration galleries in the raised beach deposits beside or beneath streams would probably be the best means of development. Horizontal galleries in trenches reaching bedrock and perpendicular to the direction of ground-water flow would intercept the greatest amount of water and would, therefore, provide the greatest yield. Methods of installing and maintaining infiltration galleries for developing shallow ground-water supplies have been described by Feulner (1964).

No analyses of water from the raised beach deposits were made during the study of the Metlakatla peninsula, but the chemical quality is probably good. Because the raised beach deposits are near the surface, they are subject to pollution; thus the area around an infiltration gallery would have to be protected. Dark color derived from decomposition of vegetation in the muskeg and muck may be a problem, although the color might be eliminated by special treatment.

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