Short Papers in Geology and Hydrology Articles 1–59

GEOLOGICAL SURVEY RESEARCH 1963

GEOLOGICAL SURVEY PROFESSIONAL PAPER 475-B

Scientific notes and summaries of investigations prepared by members of the Conservation, Geologic, and Water Resources Divisions

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1963

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

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FOREWORD

This collection of 59 articles is one of a series to be released in 1963 as chapters of Professional Paper 475. The articles report on scientific and economic results of current work by members of the Geologic, Water Resources, and Conservation Divisions of the United States Geological Survey. Some of the papers present the results of completed parts of continuing investigations; others announce new discoveries or preliminary results of investigations that will be discussed in greater detail in reports to be published in the future. Still others are scientific notes of limited scope, and short papers on methods and techniques.

Chapter A of this series will be published later in the year, and will present a synopsis of results of work done during the present fiscal year.

Thomas B. Nolan

THOMAS B. NOLAN,
Director.

CONTENTS

Article 16

POTASSIUM-ARGON AND LEAD-ALPHA AGES FOR STRATIGRAPHICALLY BRACKETED PLUTONIC ROCKS IN THE TALKEETNA MOUNTAINS, ALASKA

By ARTHUR GRANTZ, HERMAN THOMAS, T. W. STERN, and NOLA B. SHEFFEY,
Menlo Park, Calif.; Washington, D.C.

Abstract.—A tie between radioactivity and stratigraphic time scales resulted from dating the Kosina batholith. Two radiogenic methods indicate the batholith is 160–165 million years old; geologic mapping suggests emplacement between Toarcian (Early) and Oxfordian (Late Jurassic) time, and perhaps close to the Early-Middle Jurassic boundary.

Six potassium-argon ages of biotite and four lead-alpha ages of zircon, determined for a stratigraphically bracketed pluton in the eastern Talkeetna Mountains of south-central Alaska, indicate that the pluton is about 160–165 million years old. The pluton intrudes rocks of Sinemurian to Toarcian (Early Jurassic) age and was the source of many boulders in conglomerate of Oxfordian (Late Jurassic) age. The geologic record further indicates that emplacement may have begun very early in Middle Jurassic time. The data thus suggest a tie between the Toarcian-Oxfordian interval (and perhaps the Early-Middle Jurassic boundary) on the stratigraphic time scale and about 160–165 million years on the radioactivity time scale.

GEOLOGIC ENVIRONMENT

The dated rocks are from the Oshetna River drainage of the eastern Talkeetna Mountains. Half of them are from the plutonic rocks shown in the northwest part of figure 16.1—rocks which occupy a large area in the drainage of Kosina Creek to the north of the area of figure 16.1 and for convenience are called the Kosina batholith. The other half are from boulders in the Naknek Formation near the Little Oshetna River (see table 16.1 and fig. 16.1).

The Talkeetna Formation, which is intruded by the Kosina batholith, is widespread in the southern Talkeetna Mountains and consists of a thickness of perhaps 2 miles or more of predominantly marine sedimentary and volcanic rocks. It contains ammonites (identified by R. W. Imlay, written communications, 1961 and 1962) which are representative of parts of the Sinemurian, Pliensbachian, and Toarcian (including upper Toarcian) Stages of the Early Jurassic. Pectens of the genus *Weyla* from the Talkeetna (identified by S. W. Muller, oral communications, 1961 and 1962) belong to species which range through these same stages. Three of the fossil localities are between 1 and 2 miles from the batholith (fig. 16.1). Locality A (USGS Mes. loc. 28659), in hornfelsed beds intruded by an apophysis of the batholith, contains *Weyla* and is therefore of Early Jurassic age; locality B (USGS Mes. locs. 25938, 28660, 28661, 28662, and 28663), in beds within three-quarters of a mile of another apophysis, contains the ammonites *Crucilobiceras* (two species), *Acanthopleuroceras*, and *Radstockiceras*, and the pecten *Weyla dufrenoyi* d'Orbigny—an association which is of early Pliensbachian age; locality C (USGS Mes. loc. 26722) contains *Crucilobiceras* of late Sinemurian to earliest Pliensbachian age.

The Naknek Formation, deposited in the Matanuska geosyncline from early Oxfordian to late Kimmeridgian or early Portlandian time, contains abundant fresh-appearing plutonic clasts which we think originated in the Kosina batholith. These clasts occur in conglomerate beds at the base of the formation and at several higher levels. The beds contain cobbles and boulders, and some attain a thickness of 1,000 to 1,500 feet; yet, within a few miles south of their northernmost outcrops, they lens out into siltstone and shale. The boulders of plutonic rock that were dated came from about 400 feet above the base of such a conglomerate at the bottom of the Naknek Formation (fig. 16.1). This conglomerate lenses out southward into

ART. 16 *IN* U.S. GEOL. SURVEY PROF. PAPER 475–B, PAGES B56–B59. 1963.

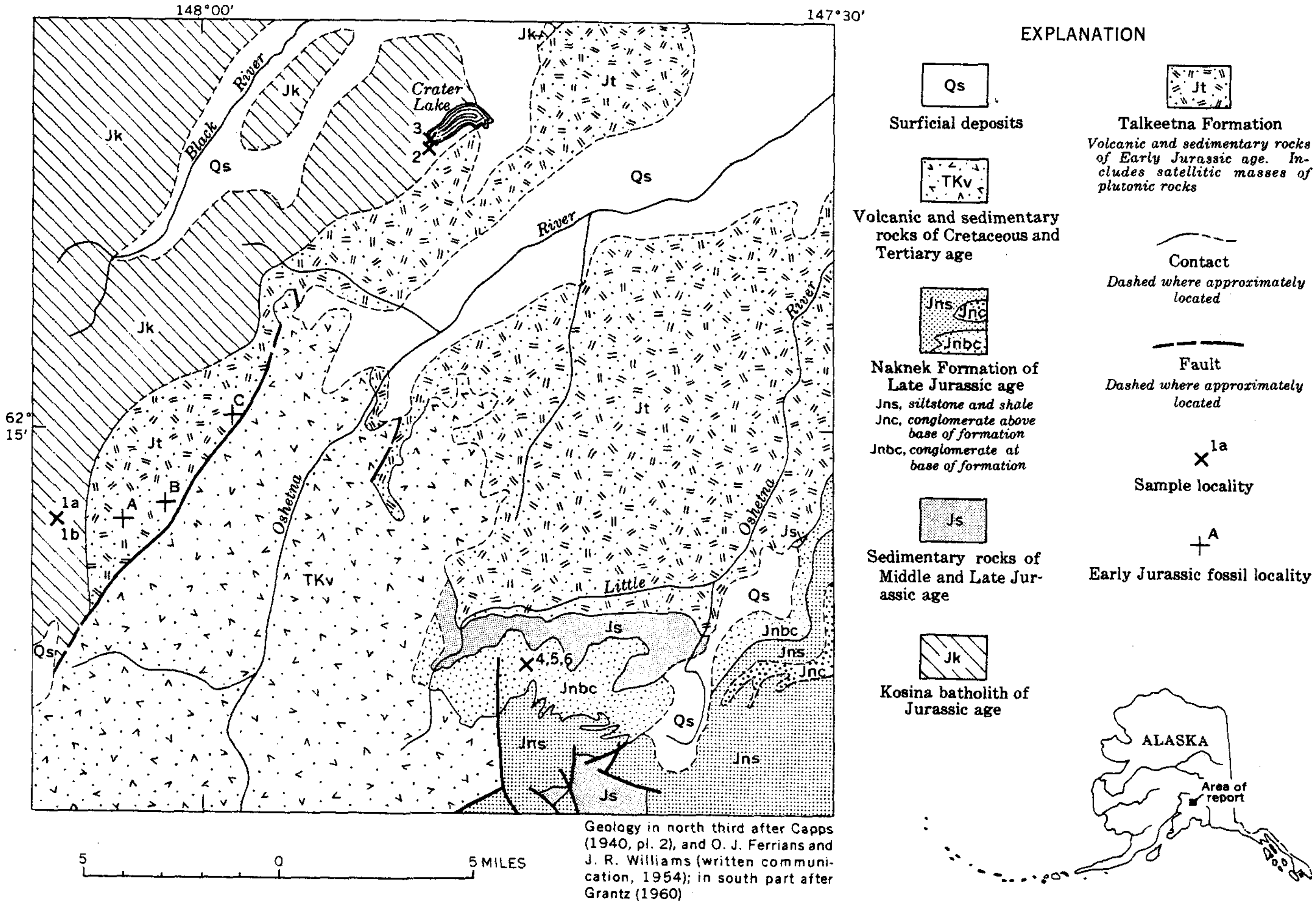

FIGURE 16.1.—Generalized geologic map of Oshetna River area, Alaska, showing location of samples dated by K-Ar and Pb-α methods, and fossil localities.

TABLE 16.1.—*Source of dated samples*

No. on fig. 16.1 and tables 16.2 and 16.3	Field No.	Rock type	Source	Locality
1a and 1b	59AGzM26	Quartz diorite-granodiorite	Kosina batholith, 4,000 ft from its southeast contact.	Talkeetna Mountains (A-3) quadrangle, lat 62°12'50" N., long 148°06'35" W.
2	59AGzM57	Granodiorite	Kosina batholith, 2,500 ft from its southeast contact.	Talkeetna Mountains (B-2) quadrangle, lat 62°21'17" N., long 147°49'12" W.
3	59AGzM58	Granodiorite	Kosina batholith, 3,000 ft from its southeast contact.	Talkeetna Mountains (B-2) quadrangle, lat 62°21'22" N., long 147°49'18" W.
4 5 6	59AGzM25-I 59AGzM25-II 59AGzM25-III	Quartz diorite-granodiorite Granodiorite-quartz monzonite. Quartz diorite.	Rounded boulders from conglomerate unit (Jnbc on fig. 16.1) at base of Naknek Formation (Late Jurassic). Boulders collected about 400 ft above base of the conglomerate at place where it is about 1,500 ft thick. Size of boulders in outcrop face: I, 2×4½ ft; II, 1×2 ft; III, 1×2 ft.	Talkeetna Mountains (A-2) quadrangle, lat 62°09'52" N., long 147°44'40" W.

siltstone containing *Cardioceras martini* Reeside of early Oxfordian age and *Buchia concentrica* (Sowerby) of late Oxfordian and early Kimmeridgian age (R. W. Imlay, written communication, 1953).

A reconnaissance study of the Kosina batholith was made by Chapin (1918, p. 42–43 and pl. 2), who reported that the intrusive body is dominantly quartz diorite. However, G. D. Eberlein (oral communication, 1962), who also made a reconnaissance study of the area, has stated that in its central part the batholith is a composite body consisting of granodiorite (with biotite the predominant ferromagnesian mineral) as well as of rocks that are more mafic and more salic than granodiorite. These include quartz monzonite containing both muscovite and biotite, amphibolite paragneiss, and tactite. In the recent study only the southeast margin of the batholith was visited. This area is richer in hornblende than the central part and is composed mainly of hornblende-biotite granodiorite, much of which borders on quartz diorite, some on quartz monzonite. (The modal classification of granitic rocks adopted is that of Moore, 1959, p. 198, which is modified from Johannsen, 1931.) Quartz diorite and diorite are also present. The approximate composition of the granodiorite is quartz, 25–30 percent; plagioclase (mainly sodic andesine), 35–50 percent; orthoclase (largely interstitial or intergrown with quartz), 5–15 percent; biotite (partly altered to chlorite), 10–15 percent; and hornblende, 10 percent. The modes cited here and below are based on point counts mainly by W. L. Griffin and M. C. Blake, of the U.S. Geological Survey. Minor accessories include opaque minerals, apatite, zircon, and sphene.

The three boulders of plutonic rock from the Naknek Formation that were dated are hornblende-biotite granodiorite and quartz diorite. Their approximate composition is quartz, 15–30 percent; sodic andesine, 35–55 percent; orthoclase, <5–15 percent; and biotite and hornblende, each about 10 percent. Opaque minerals, apatite, sphene, and zircon are minor accessories. The boulders are thus similar to the dominant rocks of the south margin of the Kosina batholith. The similarity suggests that the boulders came from the adjacent batholith; this idea is strengthened by the similarity in radioactivity ages of the boulders and the south margin of the batholith. However, on the basis of our present knowledge of the Kosina batholith and the plutonic rocks in south-central Alaska generally, their identity cannot be unequivocally established.

GEOLOGIC AGE OF THE KOSINA BATHOLITH

The Kosina batholith appears to have been emplaced between Toarcian and Oxfordian time, but the field data do not pinpoint the time of intrusion. However, possible times of emplacement are suggested by unconformities within the sedimentary section of the nearby Matanuska geosyncline (see fig. 16.2). The rocks of the geosyncline, which are dominantly marine, crop out along the southern margin of the Talkeetna Mountains and were derived from the area immediately to the north. They rest unconformably upon the Talkeetna Formation and range in age from early Bajocian (Middle Jurassic) to Maestrichtian (Late Cretaceous).

Chapin (1918, p. 43) thought that emplacement of the pluton occurred between deposition of the Chinitna Formation (Callovian) and the unconformably overlying Naknek Formation (Oxfordian), and perhaps accompanied the uplift that ended Chinitna sedimentation. Unconformities also occur beneath beds of late Bathonian age and beneath beds of early Callovian age. However, more significant than these is the unconformity between the Talkeetna Formation and the lower Bajocian rocks at the base of the section deposited in the Matanuska geosyncline. The tectonic event marked by this unconformity ended widespread Early Jurassic (Talkeetna Formation) deposition, which had been characterized by volcanism in the Talkeetna Mountains area. Within the domain of this deposition, a provenance area was created at this time in the Talkeetna Mountains, and a nonvolcanic geosyncline (Matanuska) was created in the area to the south. The Kosina batholith may have been intruded at about the Toarcian–Bajocian time boundary (Early-Middle Jurassic), because the unconformity at this boundary represents the major tectonic event of the region in the Toarcian-Oxfordian interval.

RADIOGENIC AGE DETERMINATIONS

The mean of 3 K-Ar dates (table 16.2) on 2 samples of the Kosina batholith is 165 m.y., and the mean of 3 K-Ar dates on 3 boulders of plutonic rock from the Naknek Formation is 158 m.y. The mean age of the 5 samples dated is 162 m.y. The mean of 3 Pb-α dates (table 16.3) of samples for which K-Ar dates are available is 165 m.y. Each is compatible, within the limits of analytical error, with the corresponding K-Ar date. One sample, for which no K-Ar date could be obtained, yielded a Pb-α date of 125±15 m.y. The dates

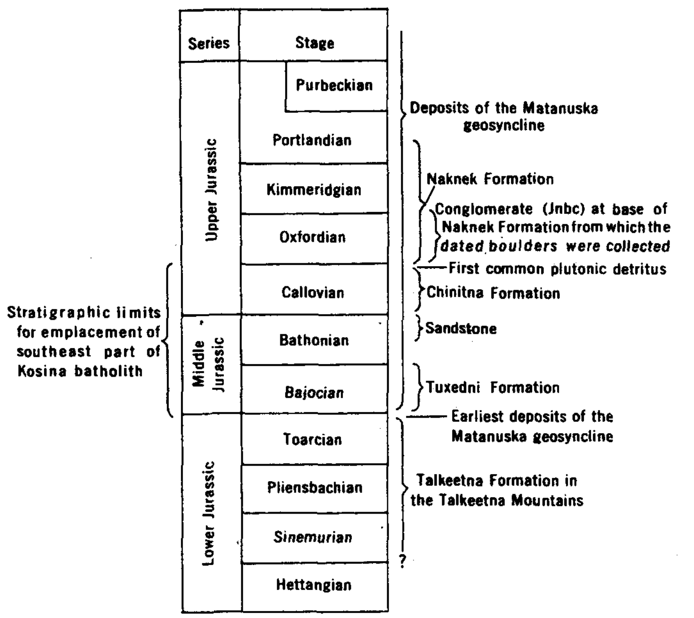

FIGURE 16.2.—Stages of the Jurassic showing stratigraphic position of the Naknek Formation and the plutonic boulders that were dated, and the inferred time-stratigraphic limits of the southeast margin of the Kosina batholith.

by the Geological Survey are reported here for the first time.

TABLE 16.2—*Potassium-argon ages of biotite from southeast margin of Kosina batholith and from boulders of similar lithology in the Naknek Formation*

[Age of sample 1a from Evernden and others (1961, p. 88, sample KA431); all other determinations by U.S. Geological Survey]

No. on fig. 16.1	K^1 (percent)	K^{40} (ppm)	Radiogenic Ar^{40} (ppm)	Radiogenic $\frac{Ar^{40}}{K^{40}}$	Calculated age (millions of years)
Samples from Kosina batholith					
1a	3.63				169
1b	3.39	4.10	0.0394	0.00961	155
3	5.60	6.76	.0710	.0105	170
Samples of boulders from Naknek Formation					
4	3.31	4.00	0.0393	0.00982	160
5	4.77	5.76	.0551	.00956	155
6	2.00	2.42	.0236	.00975	160

Decay constants:
$\lambda_e = 0.589 \times 10^{-10}$ per yr.
$\lambda_\beta = 4.76 \times 10^{-10}$ per yr.
Abundance ratio: $K^{40}/K = 0.0118$ atomic percent.

[1] Determinations by P. Elmore and I. Barlow.

TABLE 16.3.—*Lead-alpha ages of zircon from southeast margin of Kosina batholith and from boulders of similar lithology in the Naknek Formation*

[Alpha-activity measurements by T. W. Stern; spectrographic analyses of lead by Nola B. Sheffey]

No. on fig. 16.1	Alpha counts per milligram per hour	Pb (ppm)	Calculated age (millions of years)[1]
Samples from Kosina batholith			
2	300	15 (14, 16)	125±15
3	219	14.5 (13.5, 15.5)	165±20
Samples of boulders from Naknek Formation			
4	100	7.2	180±20
6	130	7.9 (8.2, 7.6)	150±15

[1] Pb-α ages (rounded to nearest 5 million years) were calculated from the equation: $t = \frac{CPb}{\alpha}$, where t is the calculated age, in millions of years; C is a constant based upon the ratio Th/U, which was assumed to be 1 in the zircon samples dated, and has a value of 2,485; Pb is the lead content, in parts per million; and α is the alpha counts per milligram per hour.

The scatter in the K-Ar dates and the difference between dates 1a and 1b may be related to the comparatively low K content of the biotites dated. This is due to the partial alteration of biotite to chlorite in the samples dated; however, the K-Ar dates obtained are thought to be approximately correct in spite of the alteration.

The difference between the mean of the batholith samples (165 m.y.) and the mean of the boulder samples (158 m.y.) is also within the limits of accuracy and may have no special significance. However, the difference is possibly due in some way to the cycle of erosion, transportation, and weathering to which the boulders were subjected in Late Jurassic time, and to the long period during which they remained buried in marine sedimentary rocks. Alternatively, it might be due to differences in the cooling history between the part of the batholith sampled in outcrop and the part represented by the boulder samples. Nevertheless, it seems best at present to consider all of the samples as one group with a mean age of 162 (160–165) m.y. This age for the emplacement of the southern margin of the Kosina batholith establishes a tie between the radioactivity and the stratigraphic time scales in the Toarcian-Oxfordian stratigraphic interval. The age of the emplacement may even approximately date the Toarcian-Bajocian boundary, and thus the boundary between Early and Middle Jurassic.

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Article 27

AERIAL RECONNAISSANCE OF THE OUTER SHUMAGIN ISLANDS, ALASKA

By ARTHUR GRANTZ, Menlo Park, Calif.

Abstract.—The outer Shumagin Islands, which jut 65 miles into the North Pacific from the western part of the Alaska Peninsula, consist of slaty argillite and graywacke of late Mesozoic age, and biotite granodiorite which has intruded them.

The outer islands of the Shumagin Islands group form a geologically distinct island subgroup, composed of slaty argillite, graywacke, and granodiorite, which projects from 25 to 65 miles into the North Pacific from the western part of the Alaska Peninsula (fig. 27.1). This subgroup comprises the islands from Nagai seaward (fig. 27.2), and extends from a point 45 miles southeast of the Aleutian arc to a point 18 miles from the outer edge of the continental shelf (arbitrarily placed at the 100-fathom depth curve) and 75 miles from the axis of the Aleutian Trench.

It is noteworthy that each major rock type in the outer Shumagins was recorded in 1741 by Georg Wilhelm Steller while serving as physician and naturalist on Bering's second voyage, the exploration which discovered Alaska.[1] These and a few other geologic observations entered in Steller's journal of this voyage establish that this noted botanist and zoologist made the first recorded geologic observations in Alaska. Grewingk (1850, p. 173 and pl. 2) noted that much clay slate ("Thonschiefer") crops out on Nagai, and his map showed this island to be underlain by metamorphic rocks. Dall (1882, repeated in Dall and Harris, 1892, p. 233, and Dall, 1896, p. 807–809) noted that the outer Shumagins were composed of granitic and metamorphic rocks, but he presented no geologic map. Atwood (1911, pl. 6) mapped the outer Shumagins as "volcanic(?)-

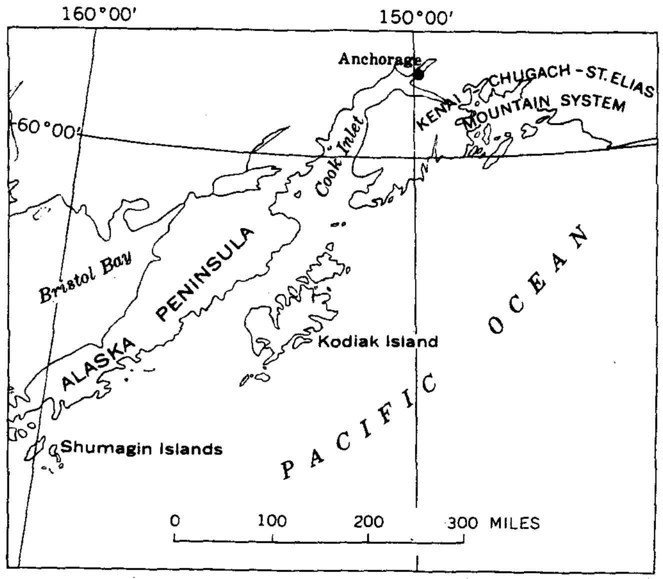

FIGURE 27.1—Index map of southwest Alaska.

unsurveyed" although he had noted Dall's observations in his text, and Atwood's map was used by Dutro and Payne (1954) in compiling their geologic map of Alaska. The present article is based upon aerial reconnaissance in the outer Shumagins from a light wheel-plane on June 12–14, 1962, supplemented by observations at three landing places and study of aerial photographs. R. V. Allen, of the U.S. Geological Survey contributed samples and (or) data on bedrock at five gravity stations which he established in the outer Shumagins in 1961.

The oldest rocks in the outer Shumagins are the slaty argillite and graywacke of Nagai, western Big Koniuji, and the smaller islands which lie between them (fig. 27.2). These rocks also form large xenoliths and probably roof pendants in the plutonic rocks on Nagai and Big Koniuji. In outcrops at Saddlers Mistake and Eagle Harbor, and in hand specimens from Pirate Shake, the graywacke is medium or medium dark gray, predominantly fine and medium grained, and thin to very thick bedded with argillite interbeds. Graded bedding, from medium sand at the base to silt at the top, is common but not conspicuous. Argillite chips of

[1] Steller's journal (in the translation by Stejneger *in* Golder, 1925, p. 79) states of Nagai and the outer Shumagins . . . "This island, as well as all the others, consists only of high solid rocks covered with vegetation. The rock is mainly a coarse, gray and yellowish graywacke (sic), in some places a gray sandstone; a black, thick slate occurs also." Steller's observations were probably made near the low valley which transects Nagai Island 9 miles from its southern tip. His gray sandstone and black slate are the medium gray graywacke and dark gray slaty argillite of Nagai Island. His graywacke as rendered in Stejneger's translation was apparently "Felsen Stein" rather than the equivalent "Graufels" in the original journal (Golder, 1925, p. 79, footnote 164) and the phrase "coarse, gray and yellowish graywacke" is thought to record the light-gray granitic rock which crops out in the sea cliffs near Steller's probable landing place on Nagai.

ART. 27 *IN* U.S. GEOL. SURVEY PROF. PAPER 475–B, PAGES B106–B109. 1963.

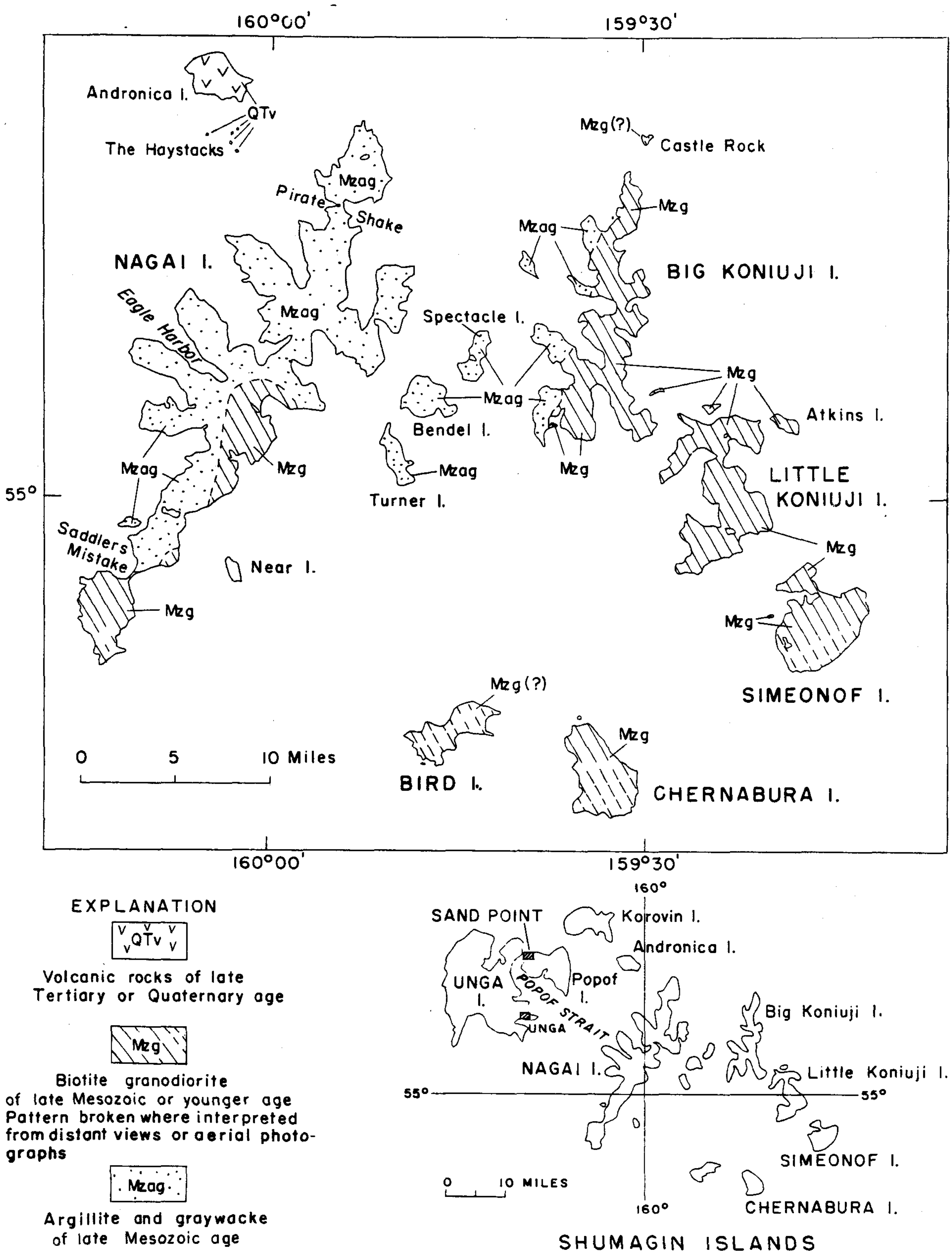

FIGURE 27.2.—Reconnaissance geologic map of the outer Shumagin Islands.

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sand to cobble size are widespread in the graywacke and locally form conglomeratic accumulations. Sole markings are not abundant but groove casts, and possible grazing marks, flute casts, and worm-tube fillings, are found. The fine-grained tops of some graded beds contain small-scale current ripple marks. The argillite is dark and very dark gray, occurs in thin to very thick beds, and in places contains thin layers of graded silt with small-scale crossbedding. Limestone concretions, small iron sulfide concretions, and thin accumulations of shells were found in a few beds.

The slaty argillite and graywacke are hard, dense, and considerably deformed. The density of six samples ranged from 2.69 to 2.74 and averaged 2.71. Diagenetic and low-grade metamorphic recrystallization have almost or entirely eliminated porosity from these rocks, and fracturing and veining are locally common, especially in the graywacke. Dips are moderate to very steep, and over most of Nagai are directed toward the northwest. Dips are equally steep but more variable in direction east of Nagai. Faults are numerous, and both open and chevron folds were noted. As seen from the air and on two ground traverses, strong axial-plane cleavage appears to be absent, but slaty cleavage was observed, especially near some faults and in argillite interbedded with thick graywacke beds.

Fossils are not abundant in the slaty argillite and graywacke, but four collections were obtained by the writer at Eagle Harbor, Nagai Island. These contain fragments of the late Mesozoic mollusk *Inoceramus* (identified by D. L. Jones) and a few rushlike plants. The indicated age and lithologic character of these rocks suggest that they are part of the similar sequence of late Mesozoic age which underlies Kodiak Island and the Kenai–Chugach–St. Elias Mountain system. In the latter areas the group names Orca, Sunrise, Valdez, and Yakutat have been variously applied to these rocks, but until their stratigraphic classification is finally established in these larger and better known areas, it seems best neither to apply the old nor to coin new names for the argillite and graywacke of the outer Shumagins.

Plutonic rocks form part of Nagai and most of Big Koinuji and the more easterly Shumagins. Their presence on Chernabura and Bird Islands is known only from one gravity station and from photogeology. As seen from the air, the plutonic rocks intrude the argillite and graywacke on Nagai and Big Koniuji Islands, and their age is therefore no older than late Mesozoic.

Samples of the pluton collected at five localities on Nagai, the Koniuji, and Simeonof Islands were examined with a binocular microscope. Four are light-gray medium-grained biotite granodiorite (classification of Johannsen, 1939) with hypidiomorphic-granular texture. The fifth sample, from the southern part of Nagai, is biotite adamellite with similar color and texture except for coarse grains of late potash feldspar. The dark minerals in all samples are chiefly reddish-brown biotite, and minor magnetite and chlorite. Four density determinations ranged from 2.63 to 2.67 and averaged 2.65. Modes of the four granodiorite samples, in volume percent, determined from stained surfaces follow:

	Range (percent)	*Average (percent)*
Quartz	24–31	28
Plagioclase	38–48	42
Potash feldspar	10–19	15
Dark minerals	13–17	15
		100

The adamellite sample contains, by volume, 32 percent quartz, 34 percent plagioclase, 26 percent potash feldspar, and 8 percent dark minerals. The uniform character and the map distribution of these rocks suggest that they are part of a batholith which extends over half the area of the outer Shumagins. This batholith is at least 20 miles in diameter and could be much larger.

Tertiary sedimentary rocks also exist, according to Dall (1896, p. 808–809), "On the western edge of Nagai . . . above the metamorphic schists and quartzites, but they are greatly altered and consolidated and constitute a small area in comparison with underlying strata." These rocks were not recognized in the present aerial reconnaissance.

The outer Shumagins differ markedly in geologic character from the inner Shumagins, which expose unmetamorphosed and in part poorly consolidated sedimentary rocks of Tertiary age overlain by pyroclastic rocks and lavas of late Cenozoic age. The latter constitute Andronica Island and The Haystacks and lie within 4 miles of the northwest part of Nagai. The inner Shumagins are thus structurally much lower than the outer Shumagins, and a flexure and (or) fault which strikes northeast and is structurally down on the northwest must lie between Nagai and The Haystacks. If Tertiary rocks crop out on Nagai, as reported by Dall, then part of this structure would cross the western part of this island.

Pleistocene glaciers covered the outer Shumagins and extended into areas now beneath the sea. The glaciers which originated on the 1,000- to 1,900-foot mountains of these islands carved cirques, tarns, and deep U-shaped valleys whose lower ends formed fiords. Postglacial marine erosion has produced wave-cut platforms around these islands and, in places, hanging cirque valleys and cliffed headlands. An elevated platform of low relief, also interpreted to be wave cut, covers three-fourths of Simeonof Island and small areas on Chernabura. Hasty reconnaissance suggests that the elevated surface was possibly formed by more than one stand of the sea. In one area on Simeonof Island the planed-off bedrock surface stands 15 to 25 feet above sea level at distances of approximately three-fourths mile from the ancient strandline. The cutting of this elevated platform may be older than the last period of glaciation in this area, for on Simeonof Island features identified on aerial photographs as glacial deposits (D. M. Hopkins and D. S. McCulloch, oral communication, 1962) appear to lie upon it. Its elevation indicates that the area of the platform that is 15 to 25 feet above sea level could be of Sangamon (last interglacial) age because Second Beach at Nome, thought to be of this age, is 35 to 40 feet above present sea level (Hopkins and others, 1960, p. 53). However, because the platform lies in a tectonically active region, its elevation is not sufficient to establish its age. The elevated platform was not recognized on the Koniujis or Nagai; if its absence is not due to subsequent glacial or marine erosion, then these islands have been depressed relative to Simeonof and Chernabura in the time since the platform was cut.

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Article 28

STRUCTURAL INFLUENCE ON DEVELOPMENT OF LINEAR TOPOGRAPHIC FEATURES, SOUTHERN BARANOF ISLAND, SOUTHEASTERN ALASKA

By DAVID A. BREW, ROBERT A. LONEY, JOHN S. POMEROY, and L. J. PATRICK MUFFLER, Menlo Park, Calif.

Abstract.—Joints, foliation, and faults influenced development of the ice-eroded deep fiords and valleys. Northwest-trending linear topographic features parallel the generalized strike of the foliation, but are locally controlled by faults. Northeast-trending linear features parallel the generalized strike of several joint sets, but are locally influenced by faults.

The rarely visited southern part of Baranof Island displays some spectacularly rugged glacial topography, including many small fiords and deep lake-filled valleys that are strikingly linear (fig. 28.1).

These dominantly ice-eroded linear features are compared to the attitudes of joint sets, foliation, and faults, which it is assumed influence the erodibility of the bedrock by providing surfaces along which the rock will break or otherwise erode more easily.

In a largely hypothetical study Twenhofel and Sainsbury (1958) inferred fault control for almost all prominent linear topographic features in southeastern Alaska, but did not exclude the possibility that some of the features could be joint controlled. Peacock (1935) concluded that the pattern of fiords in British Columbia corresponds to the underlying pattern of folds, fractures, and faults in the bedrock, but did not present detailed evidence. He emphasized (1935, p. 658) the parallelism of joint sets and physiographic features and noted also that faulting was locally important. The present study differs from these previous ones in that it is a detailed quantitative study of a much smaller area.

Southern Baranof Island consists of metamorphic rocks intruded by igneous masses believed to be satellitic to the Coast Range batholith on the mainland.

The northwestern part of the area shown on figure 28.1 is underlain by consistently northwest-striking graywacke and argillite of the Sitka Graywacke of Jurassic and Cretaceous age (Loney and others, 1963a). To the southeast this unit is intruded and thermally metamorphosed by two major granitic complexes. The northeastern part of the area shown on the illustration consists of four major igneous masses intruded into amphibolite, schist, and gneiss derived from several lithostratigraphic units of probable Mesozoic age. The distribution of these several units is shown on a forthcoming preliminary map by Loney and others (1963b). The geology of the island will be described in detail in a later report.

This study is based primarily on structural observations made from shoreline exposures during reconnaissance mapping. The pattern of fiords provides an areally even distribution of observations. The data from the intervening ridges are unevenly distributed and were not incorporated in the study, although they confirm the conclusions drawn from the shoreline data.

The field and analytical procedures used were as follows: Structural observations were taken at about 1-mile intervals along all of the coastline shown on figure 28.1. Separate pole diagrams of structures in the igneous and in the metamorphic rocks were prepared for each subarea, but because of the essential similarity of the attitudes in both types of rock the pole diagrams were combined to make the contour diagrams. Only the best developed joint set observed at each station was used in preparation of the joint diagrams. Joints dipping less than 35° were excluded from the analysis because they probably have relatively little effect on the orientation of the linear topographic features. Foliations measured in the metamorphic rocks include schistosity and closely spaced shear surfaces; a few relict bedding attitudes from unfoliated less metamorphosed rocks are also included. Foliations measured in the igneous rocks include schlieren and other mineral layering.

The data presented on figure 28.1 permit visual comparison of the structural observations with the orientation of the fiords, larger lakes, and principal streams as taken from the Port Alexander 1:250,000 Alaska Topographic Series map. In comparing the structural

ART. 28 *IN* U.S. GEOL. SURVEY PROF. PAPER 475–B, PAGES B110–B113. 1963.

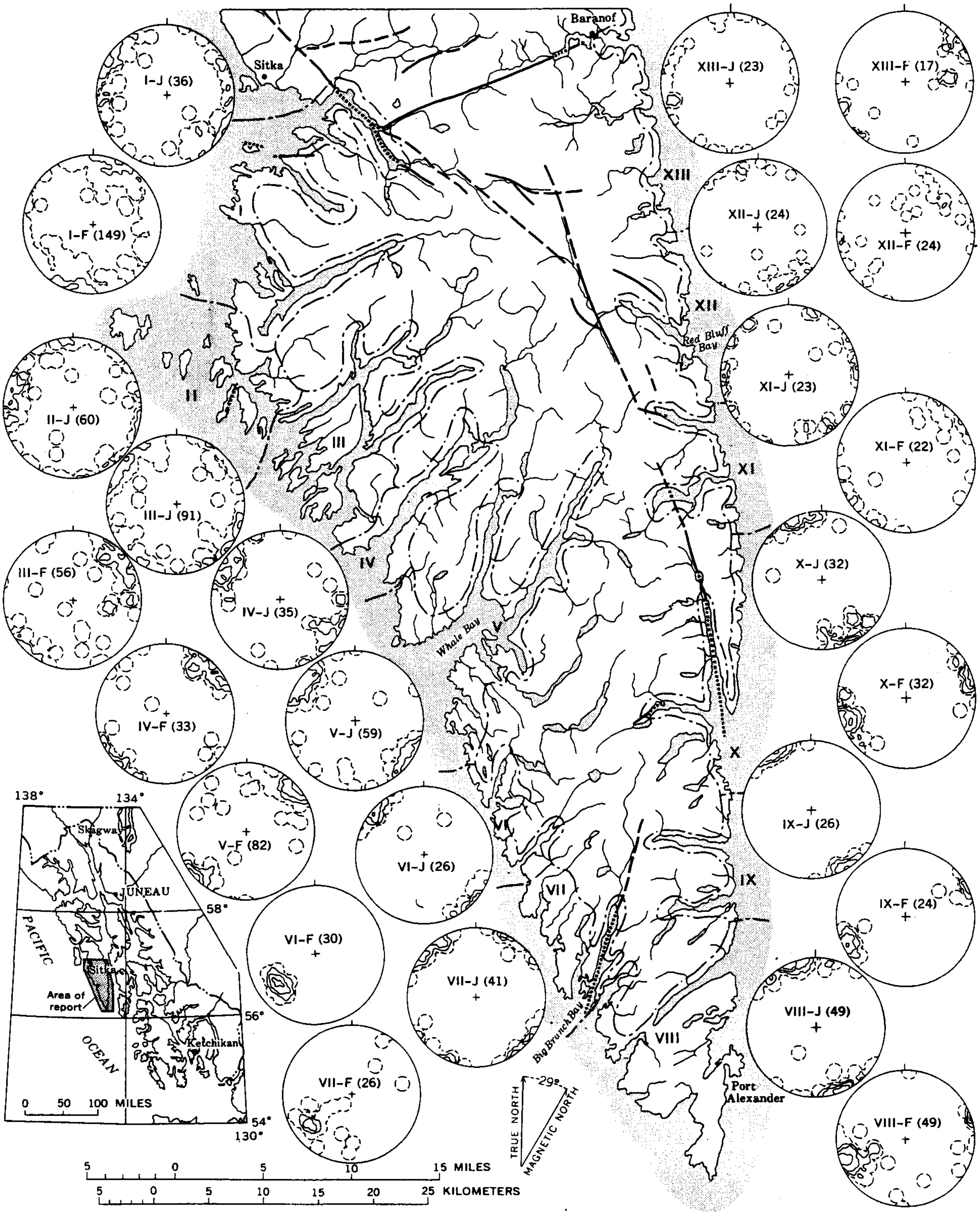

FIGURE 28.1.—Map of southern Baranof Island, southeastern Alaska, showing: fiords, lakes, streams, faults (dashed where probable); and foliation and joint attitudes for each subarea indicated by Roman numeral. Poles to foliation (F) and joints (J) shown in lower hemispheric equal-area projection; number of poles in parentheses. Solid contours indicate 5 (omitted in diagrams of 30 poles or less), 10, 20, and 40 percent per 1 percent of area. Dashed contours indicate the limit of the 1-percent circle drawn about single points.

observations and the topographic orientation, the scatter of both should be kept in mind. Rose diagrams showing the azimuth and length of fiords and valleys in each subarea were prepared for comparative purposes but are not included here because of space limitations; most of these diagrams show the expected bimodal distribution. Divergencies and apparent inhomogeneities result from the large size of the individual subareas. Although the similarity between the distribution of linear topographic features and structural elements is only approximate, the essential correspondence is within the limits imposed by the large size of the subareas and the scatter of the topographic and structural data.

JOINTS

Well-developed and persistent, generally northeast-striking joint sets in both the igneous and metamorphic rocks appear to exercise the primary influence on the northeast-trending linear topographic features. The influence of these sets is in places augmented or surpassed by near-parallel major faults, but (as shown on fig. 28.1) only a few large northeast-striking fault zones were mapped on southern Baranof Island.

The joint diagrams for subareas I–VIII on the west side and southern tip of the island show a complex system of steep northeast-striking joint sets; a few sets of different strike are important in only 1 or 2 subareas. The more diffuse diagrams generally are from subareas with greater areas of igneous rock and migmatite outcrop, in which several prominent joint sets are present and no one set is dominant. The difference in the position of the maximum of subarea VIII as compared with the maximums of the subareas to the north may reflect an areal change in lineation attitudes, as most of the joints are of the *ac* type (perpendicular to the fold axes).

The diagrams for subareas IX–XIII on the eastern side of the island demonstrate that the joint sets measured on the western side of the island extend through to the eastern side as far north as subarea X; but the pattern shown by these diagrams is disrupted to the north in the widespread intrusive and migmatite terrane of subareas XI to XIII.

The general correspondence between the strike of the dominant joint sets and the linear northeast-trending topographic features is shown on figure 28.1. This tendency toward parallelism indicates that the joints have very probably controlled the trend of these linear features. Generally northeast-trending topographic features which diverge somewhat from the strike of the joints may be caused either by the modifying influence of foliation, by faults, by local joint sets, or by combinations with joint sets of lesser development that are not represented in the diagrams.

FOLIATION

The northwest-trending linear topographic features are generally shorter than the northeast-trending features and tend to be parallel to the generalized strike of the steeply dipping foliation which ranges from N. 24° W. to N. 44° W. Foliation in the isoclinally folded Sitka Graywacke and its metamorphosed equivalents consists in many places of pre-metamorphism shear surfaces that locally form significant shear zones. Because of the isoclinal folding, the foliation and the boundaries of the original lithostratigraphic units are almost everywhere nearly parallel; it therefore is unlikely that a topographic feature controlled by an original unit would diverge appreciably from the strike of the foliation.

The diagrams of subareas I, II, and III on the west side of Baranof Island show diffuse maximums representing steeply dipping foliation that strikes between N. 65° W. and N. 30° W. The foliation diagram for subarea II is not shown because of extreme scatter, probably due to the rotation of the foliated xenoliths within the igneous mass. Diagrams V to IX show simpler, more marked preferred orientations that are due to the lesser amounts of igneous rock involved and to the more uniform deformation recognized in these subareas. The rocks of subarea VIII are strongly lineated, and the lineation may have influenced the erodibility of the bedrock through its modifying effect on the foliation. In the diagrams for subareas X to XIII the northwest- and west-northwest-striking pattern is continued, but is generally more diffuse because of large areas of igneous and mixed igneous and metamorphic rocks in those subareas.

FAULTS

A few major and several minor faults have been mapped on southern Baranof Island (fig. 28.1). More detailed mapping would undoubtedly reveal many more minor faults and possibly a few more major faults. Almost all of the faults shown on the illustration have associated shear zones that influenced the erodibility of the bedrock locally, in many places extensively enough to be expressed on a topographic map at a scale of 1:63,360 or even smaller. At Big Branch Bay the existence of a fault is inferred from the offset of geologic contacts across the bay. This is the only northeast-trending fiord where such offset is present.

The pattern of the demonstrated faults indicates that the number of faults striking in the northeast quadrant is about equal to that in the northwest and that the strike of these structures is reflected topographically in their immediate vicinity. It is apparent, however, that most of the fiords and deep valleys do not occur on the major faults or their extensions.

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Article 38

INFLUENCE OF SNOW COVER ON FROST PENETRATION

By DANIEL B. KRINSLEY, Washington, D.C.

Abstract.—Frost penetration is most effective through the thinnest snow cover, and proceeds more rapidly in gravel and sand than in silt or clay. Observations in Alaska, Wisconsin, and U.S.S.R. suggest that an increase of 1 to 4 inches in the thickness of a 6-inch snow cover significantly dampens the fluctuation of the ambient air temperature.

Three thermocouple cables were installed in the vicinity of Buffalo Center, Tanana Valley, Alaska, during September 1961. Each cable contained thermocouples at the ground surface and at depths of 6, 12, 18, 24, 36, and 48 inches. The sites were inspected during the first and third weeks of October, and at about 2-week intervals from November 24 to February 17, 1962. Soil temperatures at the thermocouples were read directly from a calibrated potentiometer connected to the thermocouple cable. In addition to the thermocouple data, air temperature and snow depth were recorded at each site.

Site A, three-tenths of a mile south of the Little Gerstle River and approximately 50 feet above the stream channel, is adjacent to milepost 1388 of the Alaska Highway and is at an altitude of 1,300 feet. This well-drained area has been burned over, but currently is densely vegetated with black spruce, white spruce, and willow. The trees range from 15 to 25 feet in height, and the understory consists of low bushes and a mat of berries and grasses. Beneath the 2-inch-thick organic mat, glaciofluvial silt with several scattered thin gravel layers overlies coarse outwash gravel at a depth of 10 feet. No permafrost was found, and the water table is at least 20 feet below the ground surface (on the basis of exposed gravel pits in the vicinity).

Site B, 14 miles from site A and at an altitude of 1,220 feet, is located on a sand dune adjacent to milepost 1402. The dune is composed of medium sand and is stabilized by a dense forest of poplar and birch 20 to 30 feet in height. A 2-inch-thick organic mat composed of berry plants and vegetable fibers covers the sand, which is underlain by outwash gravel at a depth of 20 feet. No permafrost was found, and the water table is at least 25 feet below the ground surface (on the basis of exposed gravel pits in the vicinity).

Site C, 19 miles from site B and 33 miles from site A, is 300 feet west of the headquarters building at Fort Greely and is at an altitude of 1,280 feet. Dense stands of white spruce and birch, 20 to 30 feet in height, and a 2-inch-thick organic mat cover the site. The soil consists of 3 feet of eolian silt overlying coarse outwash gravel. Permafrost was not found, but it has been found previously in discontinuous irregular bodies at least 25 feet below the ground surface in the outwash gravel at Fort Greely (Holmes and Benninghoff, 1957, p. 169). The ground-water table has been found to range from 184 to 215 feet below the ground surface (Holmes and Benninghoff, 1957, p. 173).

The average air temperature during September 1961 [1] was 43.4°F, a departure of −2° from the 1943–60 mean.[2] The snow cover on September 30 was 1 inch thick. The average temperature during October 1961 was 19.5°F, a departure of −5.7° from the 1943–60 mean. By October 31, the snow cover was 19, 15, and 6 inches thick at sites A, B, and C, respectively. September was a climatologically normal or average month, but October was colder and had more snowfall and residual snow than the average October of the 17-year record. There were two periods of below-zero temperatures during October, each preceded and accompanied by snowfall. These periods occurred during the second and last weeks of the month.[3]

Ice appeared on the Tanana River and Jarvis Creek (adjacent to Fort Greely) on October 12 (U.S. Weather Bureau, 1962), which is normal for the area. Simultaneously, most of the ponds froze and flow ceased in several creeks. The soil at site C was frozen to a depth of 3 inches but it was not frozen at sites A or B.

During the third week in November, snow cover at sites A, B, and C was 19, 15, and 6 inches thick, respectively. These thicknesses increased 2 inches at each

[1] All air temperatures were recorded at the Fort Greely recording station, 0.6 mile from site A.

[2] U.S. Army Signal Corps Meteorological Team, 1961, Climatology chart: Fort Greely, Alaska, Nov. [Duplicated report]

[3] U.S. Army Signal Corps Meteorological Team, 1961, Monthly climatological summary: Fort Greely, Alaska, Sept., Oct. [Duplicated report]

ART. 38 *IN* U.S. GEOL. SURVEY PROF. PAPER 475–B, PAGES B144–B147. 1963.

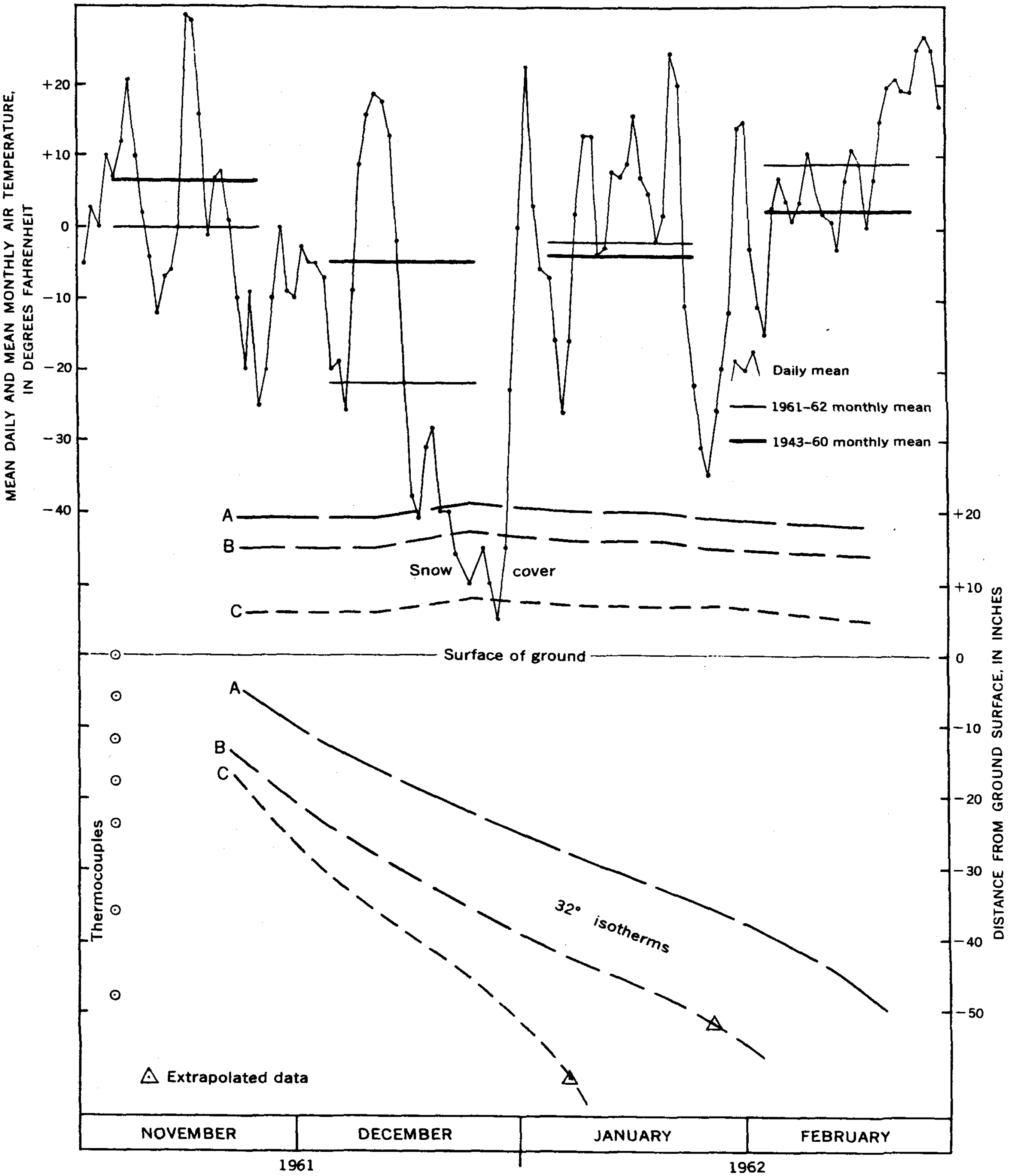

FIGURE 38.1.—Mean daily and mean monthly air temperatures recorded at Fort Greely, Alaska; snow thickness and 32° isotherms at sites A, B, and C.

site during the second half of December, and then decreased 3 inches at each site during January and February (fig. 38.1). The snow was light, dry, and free of packing or crusting at all sites. November was 6.3° colder than normal (1943–60 mean); December was 17.2° colder than normal; and both January and February were 2.0° and 6.4°, respectively, warmer than normal.[4]

The air temperature at site C was generally within 1° of the air temperature at the Fort Greely recording station (fig. 38.1). Above −13°F the air temperature at site C was always 2° to 3° lower than the air temperature at site A or B (which were generally identical); below −13° F it was always 2° to 3° above the air temperature at site A or B. All observations at the thermocouple sites were generally made during the hours 0800 to 1200.

The mean temperature at the snow-ground interface for the period November 24 through February 17 was 26.1°, 19.6°, and 1.1°F at sites A, B, and C, respectively. The mean air temperature during the period November 24 through February 17 was −8.3°F. According to Lachenbruch (1959, p. 29), "In the Arctic the mean winter temperature of the snow surface is generally probably somewhat lower than the corresponding air temperature because of the high emissivity of snow for long wave lengths." If it is assumed that the air-snow interface had a mean temperature (November 24 through February 17) of approximately −9.0°F, then the mean temperature difference between the air-snow and snow-ground interfaces was 35.1°, 28.6°, and 10.1° at sites A, B, and C, respectively.

Frost penetration proceeded most rapidly at site C, which had the thinnest snow cover (fig. 38.1). Curve C steepens considerably after the 32° isotherm passes through the eolian silt at a depth of 36 inches and enters coarse outwash gravel. This is in accord with the observations made at Dow Field, Bangor, Maine (U.S. Army Corps of Engineers, 1947) and at Portland, Maine (Fuller, 1940) that frost penetration was faster in gravel and sand than in silt and clay. It seems reasonable to assume that curve B would have been closer to curve A if the material at site B had been silt rather than medium sand. Conversely, if there had been an identical snow thickness at all sites, curve B would have been below curve C at depths less than 36 inches, but would have crossed curve C somewhere below 36 inches.

Observations at site B indicate that although its snow cover was 2.3 times as thick as that at site C, the insulating effect of the snow was 2.9 times as great as that at site C (table 38.1). The snow cover at site A was 2.9 times as thick as that at site C, but the insulating effect of the snow was 3.5 times as great as that at site C. Although visual inspection of the snow at the three sites did not reveal any density differences, layers, or crusts, the existence of these differences cannot be discounted in the absence of more precise measurements.

[4] Idem, Nov. 1961–Feb. 1962.

TABLE 38.1.—*Summary of ratios of snow thickness, mean temperature differences between the air-snow and snow-ground interfaces, and mean frost penetration*

Site	Ratio of mean snow thickness (fig. 38.1)	Ratio of mean temperature difference between snow-ground and air-snow interfaces (insulation)	Ratio of mean frost penetration (Nov. 24–Jan. 7) (fig. 38.1)
A	2.9	3.5	1.0
B	2.3	2.9	1.5
C	1.0	1.0	2.2

Examination of table 38.2 discloses the existence of a significant break in the insulating effect of snow at thicknesses between 6 and 7 inches. This break has been referred to as the "critical thickness" of snow, which may be defined as the amount of snow cover required to significantly dampen the fluctuations of the ambient air temperature. The critical thickness of snow has been observed by others (table 38.3).

TABLE 38.2.—*Differences in temperature between the air-snow and snow-ground interfaces at site C*

Date	Mean temperature of air-snow interface (degrees Fahrenheit)	Total fluctuation within period (degrees Fahrenheit)	Snow-depth (inches)	Temperature of snow-ground interface (degrees Fahrenheit)	Total fluctuation within period (degrees Fahrenheit)	Difference in temperature between air-snow and snow-ground interfaces (degrees Fahrenheit)
Nov. 24	−9.7	28.0	6	4	14	13.7
Dec. 11	18.3		6	18		.7
Dec. 26	−45.7	53.0	8	−5	8	40.7
Jan. 7	−26.7		7	0		26.7
Jan. 20	7.3		7	−2		9.3
Jan. 27	−26.7		7	3		29.7
Feb. 17	−.3		5	4		4.3

The insulating quality of snow is an expression of its thermal conductivity. This value is difficult to measure, and it depends on density, structure, texture, and interstitial air flow (Bader, 1962, p. 58). In addition, the thermal conductivity of snow is sensitive to the thermal properties of the underlying material (Lachenbruch, 1959, p. 24). In view of all these variables and the widely scattered observations (table 38.3), it is remarkable that the critical thickness of snow appears to occupy such a narrow range of values.

TABLE 38.3.—*Critical thickness of snow observed in this and other studies*

Source	Location	Mean annual temperature (degrees F)	Minimum temperature in year of observation	Critical thickness (inches)
Krinsley (this report).	Buffalo Center, Alaska.	25.7	−61 (1961)	6–7
Pruitt (1957).	Fairbanks, Alaska.	24.7	−55 (1956)	6–8
Kabanov (1937).	U.S.S.R.	------	------------	8–10
Atkinson and Bay (1940).	La Crosse, Wis.	46.3	−38 (1936)	10

The data summarized in tables 38.1 and 38.2 suggest that the transfer of heat through dry snow is reduced abruptly when a critical thickness is attained. The measurement of the exact rate of reduction at critical thickness and the explanation for this phenomenon are worthy of further study.

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Article 52

SEASONAL CHANGES IN THE CHEMICAL QUALITY OF SHALLOW GROUND WATER IN NORTHWESTERN ALASKA

By ALVIN J. FEULNER and ROBERT G. SCHUPP, Anchorage and Palmer, Alaska

Work done in cooperation with the U.S. Air Force, Alaskan Air Command

Abstract.—Marked increases in mineralization of ground water during the colder months are accounted for by simple concentration by freezing, and by reduction in dilute recharge during winter.

Data on the quality of shallow ground water at a site in northwestern Alaska indicate that marked systematic changes occur throughout the year. These changes are believed due to dilution of mineralized ground water by melt water and precipitation in the summer and by concentration of mineral constituents in the water through freezing during the winter. The data consist of analyses of a series of water samples collected during the period June 1961 to July 1962 at a remote site near the Bering Sea in northwestern Alaska, just south of the Arctic Circle. The water supply was developed during the late summer of 1961 by the U.S. Air Force; the analyses were made to rate the water for use as boiler feed and to determine what treatment, if any, would be required to make it suitable for that use.

Although permafrost is known to extend to a depth of 1,000 feet or more in this part of Alaska, water at the site described here remains fluid throughout the year in a permeable zone—most likely fractured rock along a high-angle fault which trends northward into the nearby mountains (fig. 52.1). The occurrence of springs in summer marked by ice mounds in winter suggested the possibility of developing a year-round water supply from this permeable zone. The temperature of the spring water was reported to be 35°–36°F in August 1959. The explanation of the year-round fluidity of the water has not been determined. It is unlikely that the water rises from a great depth or has been in contact with incompletely cooled igneous rocks; if such were the case, the water probably would be more highly mineralized than it is. More likely, the water is derived from precipitation and snowmelt in the nearby mountains, and because of its relatively high velocity through the permeable zone it does not freeze completely.

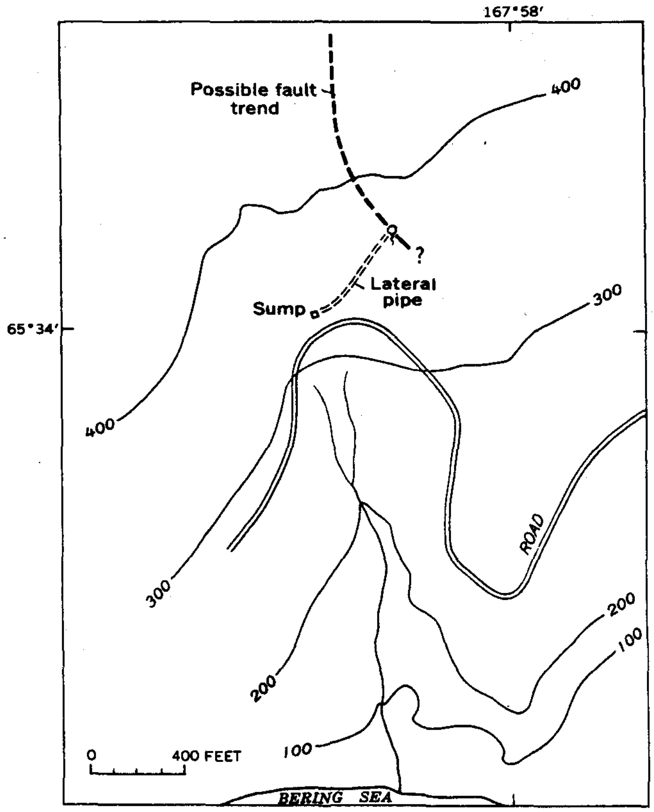

FIGURE. 52.1.—Sketch map showing fault, spring, and water-supply installations; datum mean sea level.

ART. 52 *IN* U.S. GEOL. SURVEY PROF. PAPER 475–B, PAGES B189–B191. 1963.

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A water supply was developed by excavating a trench into the permeable zone, placing perforated pipe along the bottom of the trench, and backfilling the excavation. Water entering the perforated pipe flows by gravity through a lateral pipe nearly 400 feet long to a sump (fig. 52.1) from which it is pumped for use. To prevent freezing of the water enroute to the sump, steampipes were laid along the full length of the lateral pipe, which was laid in the bottom of a trench excavated by blasting frozen bedrock.

During the coldest months the inflow of water to the sump declines, because recharge to the permeable zone virtually stops and because of freezing inward from the boundaries of the permeable zone. The discharge to the sump has ranged from several hundred gallons per minute for short periods to a low of 1,000 gallons per day in late May 1962. The area lacks a well-defined drainage system; the nearest stream, which flows only during the warmer part of the year, is about 600 feet away and downslope from the permeable zone; thus recharge is chiefly from infiltration of snowmelt and rain.

Water samples were collected by Air Force personnel for chemical analysis by the Geological Survey in June, September, and December 1961 and in January, February, April, May, June, and July 1962. Of these, the first and second were collected before installation of the water-supply system was completed. All the analytical results are given in the accompanying table, and selected results are shown in figure 52.2.

As may be seen by examination of the table and figure 52.2, the chemical quality of the water changed systematically during the period of sampling. For example, the sulfate content was 5 ppm (parts per million) or less in June and September 1961, increased to more than 40 ppm by late April and early May 1962, and dropped to 6 ppm by early July 1962. The noncarbonate hardness showed a similarly wide range—as low as 6 ppm in September 1961 and 5 ppm in July 1962, but about 10 times as great in April and May 1962. The

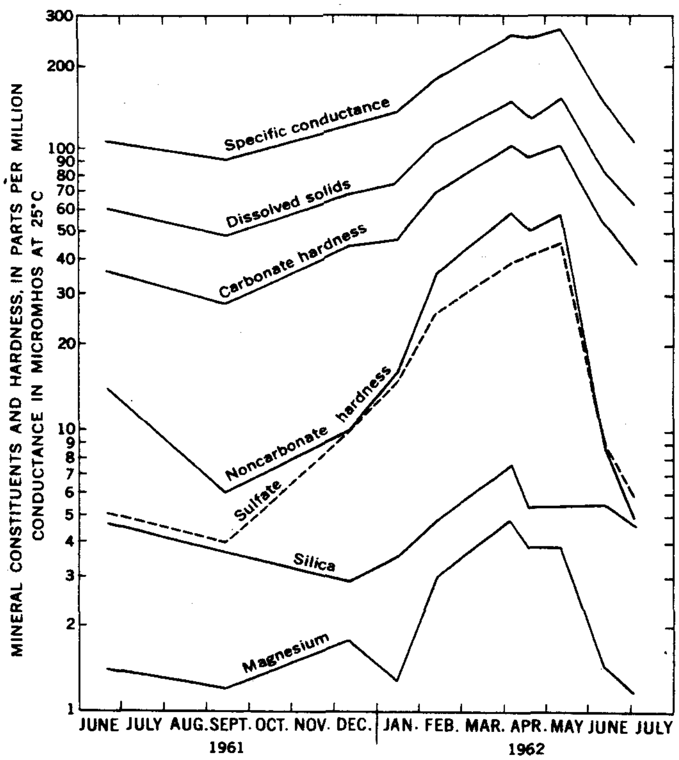

FIGURE 52.2.—Changes in the chemical quality of the water during the period June 1961 to July 1962.

differences between the summer and winter concentrations of magnesium, silica, and dissolved solids, in the summer and winter carbonate hardness, and in the summer and winter specific conductance follow a similar trend.

The mineral constituents most likely to show a wide range in concentration probably are determined by the kinds of water-soluble minerals with which the water has come into contact. At this particular site, where the summer and winter concentrations of sulfate differ so widely, the ground water has percolated through partly metamorphosed thin-bedded limestone intruded

Mineral constituents, in parts per million, and other characteristics of ground water at a site in northwestern Alaska

Date of collection	Silica (SiO_2)	Iron (Fe)	Manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate HCO_3	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue on evaporation at 180°C)	Hardness as $CaCO_3$		Specific conductance (micromhos at 25°C)	pH	Color
														Carbonate	Noncarbonate			
1961																		
June 20	4.6	0.05	0.00	12	1.4	6.9	0.3	27	5.0	16	0.6	0.4	60	36	14	106	7.2	0
Sept. 14	3.7	.00	.00	9.2	1.2	6.1	.4	26	4.0	11	.6	.2	49	28	6	92	7.1	5
Dec. 11	2.9	.02	.02	15	1.8	6.7	.1	42	10	10	.8	.6	69	45	10	122	7.1	0
1962																		
Jan. 15	3.6	.02	.00	17	1.3	7.2	.1	39	15	11	1.0	.3	76	48	16	138	7.2	0
Feb. 12	4.9	.02	.00	23	3.0	8.1	.5	42	26	16	1.3	.9	105	70	36	180	7.8	0
Apr. 5	7.8	.02	.01	33	4.9	10	.6	53	39	25	.7	2.9	150	103	59	258	7.4	5
Apr. 20	5.4	.02	.00	31	3.9	11	.6	53	42	21	1.0	1.7	131	94	51	253	7.3	0
May 10	5.4	.02	.00	35	3.9	11	.7	56	46	21	.8	1.9	154	103	58	270	7.7	0
June 12	5.5	.02	.00	19	1.5	7.5	.6	55	9.0	11	.4	1.9	83	54	9	146	7.4	5
July 3	4.7	.07	.00	14	1.2	6.8	.4	43	6.0	9.0	.5	.8	64	40	5	107	7.3	0

by granite. Pyrite, pyrrhotite, fluorite, and sphalerite are common in the mineralized zones along the contact of the limestone with the granite. Sulfate compounds formed during weathering of these and other sulfide minerals are dissolved readily in the ground water. The relative enrichment of the ground water in calcium and sulfate in the later winter months probably is due to the fact that recharge from precipitation ceases and the discharge from the permeable zone consists almost entirely of ground water that has long been in contact with mineralized rocks. The recharge from precipitation, which has a relatively high sodium and chloride content owing to proximity to the Bering Sea, is cut off during the winter as soon as the ground freezes. The increases noted in sodium and chloride probably are due to simple concentration by freezing whereas the larger increases in calcium and sulfate are due in part to concentration by freezing but also to the fact that the winter discharge has been in contact with the rock materials longer. Sparse data from another Air Force station in Alaska, where the bedrock consists wholly of limestone, indicate that there the greatest seasonal differences in the chemical quality of the ground water are in the concentrations of calcium and bicarbonate and in the carbonate hardness, and are caused by a combination of the processes similar to those described above. R. M. Waller (U.S. Geological Survey, oral communication, 1962) reported observing similar wintertime increases in mineral content in ground water flowing beneath a frozen stream in another part of Alaska.

As shown by figure 52.2, the mineral content of the water was lowest during the summer, increased gradually during the fall, increased relatively rapidly during the winter and early spring, and then declined very rapidly in the late spring to about the same level as that of the previous summer. Concurrent with the more rapid increase in mineralization was a marked decline in the yield of the water-supply system. The decline in yield presumably was caused partly by a freezing inward from the sides and downward from the top of the aquifer, thus reducing the cross sectional area through which the water could flow. This freezing accentuates the normal seasonal decline in yield, which is due to lack of recharge from precipitation in the winter and to depletion of the water in storage in the aquifer. The increase in mineral content was caused partly by selective concentration of mineral matter in the unfrozen water. The freezing accentuates a normal seasonal increase in mineral content, which is due to a reduction in the diluting effect of recharge from precipitation. Thus, in an aquifer 20 feet thick, freezing extending 15 feet into it may result in a doubling or tripling of the dissolved-solids content in the water that remains unfrozen. The rapid decline in the mineral content of the water in the late spring is related to the thawing of the ice within the aquifer, plus infiltration of surface melt water which recharges the aquifer. The double peaks on several of the curves in figure 52.2 probably indicate that at least one slight thaw preceded the main thaw in the spring of 1962; that the thawing proceeded by stages is confirmed by air-temperature data. As the water level in the sump is reported to have risen markedly on May 28, 1962, it may be reasonable to assume that the maximum mineral concentration of the ground water was reached shortly before that date.

Although documentation is sparse, probably other shallow ground-water supplies in subarctic and artic areas are subject to similar marked seasonal changes in chemical quality. Several factors—such as the depth of freezing before the snow cover becomes well established, the total moisture content of the snow cover, and the length of time the ground is snow covered—may affect the amount of increase in the concentration of dissolved minerals somewhat. However, it seems unlikely that the extremes would differ more than 10 percent from the values reported here. The observed changes are believed sufficiently representative to provide a basis for predicting the type of treatment that boiler-fed water may require at different times during the year.