GEOLOGICAL SURVEY RESEARCH 1970

Chapter C

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Scientific notes and summaries of investigations in geology, hydrology, and related fields

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GEOLOGICAL SURVEY RESEARCH 1970

This collection of 42 short papers is the second published chapter of "Geological Survey Research 1970." The papers report on scientific and economic results of current work by members of the Conservation, Geologic, Topographic, 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 1970, together with lists of investigations in progress, reports published, cooperating agencies, and Geological Survey offices.

"Geological Survey Research 1970" is the eleventh volume of the annual series Geological Survey Research. The ten 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

DETRITAL GOLD AND SEDIMENTS IN NUKA BAY, ALASKA

By ERK REIMNITZ, ROLAND von HUENE, and F. F. WRIGHT,[1]
Menlo Park, Calif., College, Alaska

Abstract.—A marine geological investigation of Nuka Bay, a fiord system along the northern Gulf of Alaska, was conducted to learn more about the possible occurrence of gold placers on Alaskan shelves and about fiord sedimentation in general. Sediment types, distribution, and thicknesses were outlined by examining 28 bottom samples and a dense pattern of seismic reflection profiles. Nuka Bay is considerably deeper than the adjacent shelf. Holocene marine sediment occurs in thicknesses of nearly 300 m in individual depressions. These sediments are dominantly clayey silt. Sand and gravel are deposited in small, steeply sloping deltas and in recent moraines. Relict sand and gravel, deposited by former glaciers, are exposed on the adjacent open shelf. Numerous streams feeding Nuka Bay carry gold, yet the bottom mud in the bay contains no gold. A small amount of gold was detected in two samples of relict gravel and in relatively unsorted coarse material dumped into the head of the fiord by a glacier. The gold apparently moves with the coarse fraction of the sediment supply and is retained in deltas and moraines where there is little chance of finding an economic concentration.

Numerous fiords indent the coast of the Gulf of Alaska, and many of these, including Nuka Bay, still have tidal glaciers. Sedimentary processes in fiords are not well understood. In 1968 an investigation of Nuka Bay was conducted by the U.S. Geological Survey in cooperation with the University of Alaska. The Nuka Bay area was chosen partly because of the occurrence of gold in the drainage basin and partly because of the recent formation of a new fiord arm by ice retreat, giving the bay special interest for marine geologists. In this report the gold potential of the marine environment in Nuka Bay is evaluated.

METHODS OF INVESTIGATION

The RV *Acona* of the University of Alaska was the operational base for the investigation. This ship was equipped with a Teledyne sparker type continuous reflection-profiling instrument and a Litton Mark 14 Precision Depth Recorder. Sampling devices used include a piston corer, a Shipek sampler, and a bucket dredge. The ship was positioned largely by radar ranges and bearings.

Sediment grain-size distribution was studied by a combined pipet and settling-tube method; sieves were used to size gravel fractions. All surface-sediment samples were analyzed for gold content by atomic absorption. For these analyses, sediment samples weighing between 300 and 5,000 g (dry weight) were available. Each sample was separated into several size classes, and each class was analyzed individually.

GEOGRAPHIC AND GEOLOGIC SETTING

The long precipitous arms of Nuka Bay, whose depths are much greater than those of the open Continental Shelf, empty into a wide bay (fig. 1). The entrance to this bay is partly exposed to the open sea and is rimmed by a broad shoal at about 125 m depth, presumably a terminal moraine. A very conspicuous moraine at an average depth of about 10 m separates McCarty Arm from the rest of the bay. The entire arm was occupied by a glacier in 1912, and probably later. This glacier still extends to tide level and still is retreating. McCarty Arm, being in the initial and probably most rapid phase of fiord filling, allows us to infer the nature of the lower part of the sediment fill in more mature fiords of the bay. This sediment, being beyond reach of available sampling techniques, can only be seen in our seismic records. Glacial streams crossing small deltas are found along the flanks of the older parts of the fiords.

Geologically, Nuka Bay is in a Cretaceous(?) slate-graywacke belt. Interbedded slate and graywacke have been regionally deformed into open, overturned folds and are intruded by granodiorite plutons and associated dikes and sills (Richter, 1968). Numerous quartz veins

[1] University of Alaska, College, Alaska.

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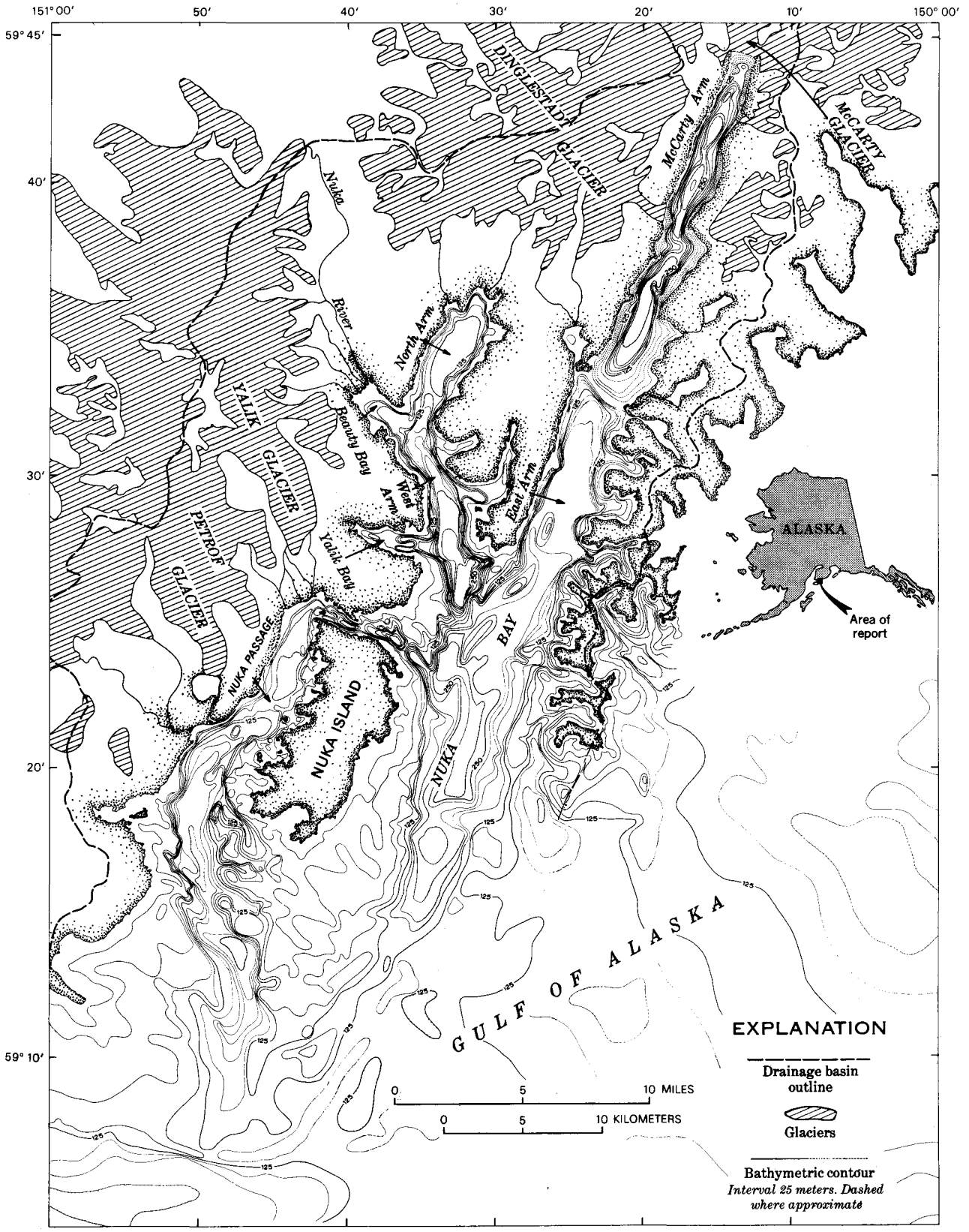

FIGURE 1.—Map of Nuka Bay area, Alaska, showing present extent of glaciers, outline of the drainage basin, major streams, and bathymetry. The bathymetry has been compiled from U.S. Coast and Geodetic Survey chart 8530 and sounding lines shown on figure 2.

containing significant amounts of gold occur in a 6- by 8-mile area around North Arm and West Arm. Total production since 1920 is estimated at $166,000. The streams contributing gold to this part of Nuka Bay and the gold-bearing lodes are shown in figure 4.

OCEANOGRAPHIC SETTING

Very little is known about the hydrology of Nuka Bay. Maximum tide range is 3.6 m, and tidal currents of 8 km/hr are reported in restricted passages (U.S. Coast and Geodetic Survey, 1964). The direct effect of tidal currents on the deep fiord bottoms is not known. Hydrographic studies of Alaskan fiords similar to those of Nuka Bay indicate that, despite the presence of shallow sills, the anoxic condition often found in the water of more temperate fiords does not exist in Alaskan fiords (Picard, 1967). Well-defined plumes of extremely turbid water, observed during the cruise of the RV *Acona* (July), were restricted to within 1 km of river mouths or glaciers. The turbid layer in Beauty Bay was less than 3 m thick, and performance of the sparker indicated saline water immediately below the turbid layer. Nuka Bay is well protected from dominant southeasterly storms except at the southeast shore of Nuka Island, where a terrace apparently is forming at a depth of about 50 m. A long sandspit at the terminus of Petrof Glacier suggests local northerly longshore currents along the partly exposed shore of Nuka Passage.

BOTTOM SEDIMENTS

More than 750 km of continuous seismic profiles (fig. 2), some of which were made in 1965 (von Huene, 1966), show the sediment distribution in Nuka Bay. These records were used to construct an isopach map of the horizontally stratified bottom sediment (fig. 3). Sediment fill of the fiords consists of a number of separate pockets of varying thickness and at different depths below the sea surface. These sediment pockets are interpreted as representing Holocene marine deposits (von Huene, 1966). In comparing the bathymetric contours (fig. 1) with the isopachous contours, we find that the sediment pockets coincide with deep, relatively flat parts of the fiords. Such pockets of Holocene sediment extend only a short distance beyond the mouth of Nuka Bay. Seaward, apparently, glacial drift of Wisconsin age and of great thickness is exposed at the bottom (von Huene, 1966).

In a typical fiord cross section, the steep mountain flanks continue below sea level to a flat, featureless bottom. The juncture of the fiord floor and walls generally is a sharp break, but in some places slump features seem to be indicated by seismic profiles (von Huene, 1966).

Twenty-eight sediment samples were collected for the present investigation. At several stations on the open shelf, where the presence of glacial drift at the surface was indicated by seismic records, a bucket dredge was used, but most samples were collected with a piston corer and (or) a snapper. Cores as long as 2.5 m were obtained. Sample 28 was collected at about sea level at the terminus of McCarty Glacier. Station locations are shown on figure 4. The percentages of gravel, sand, silt, and clay in surface-sediment samples are given in table 1.

The bottom sediment can be divided into two distinct classes: (1) Clayey silt with a small amount of sand occurs within basins outlined on the isopach map. The sand fraction of the clayey silt, which commonly consists largely of foraminiferal tests, ranges from 0 to 15 percent. (2) On the open shelf seaward of the basin, the surface sediment contains 9–95 percent gravel with some sand. The sand fraction in the gravel also consists predominantly of foraminiferal tests and consequently has a high $CaCO_3$ content.

Detailed core analyses, including a study of X-ray photographs, show that the surface sediment generally represents a subsurface condition. However, thin sandy

TABLE 1.—*Percentages of clay, silt, sand, and gravel, and gold content in surface sediment*

[Location of sampling stations on figs. 2 and 4. Gold analyses by atomic absorption. N.d. means gold was not detected]

Sampling station	Clay	Silt	Sand	Gravel	Total gold (parts per billion)
1	14.8	19.8	55.4	10.0	N.d.
2	9.8	6.2	53.6	30.5	N.d.
3	9.8	11.3	38.2	40.7	N.d.
4	11.1	8.3	36.2	44.4	N.d.
5	23.2	16.5	32.3	28.0	4
6	17.8	13.4	39.0	29.8	N.d.
7	34.2	23.1	25.7	17.0	N.d.
8	12.5	9.5	31.2	46.8	N.d.
9	.0	.0	4.6	95.4	N.d.
10	23.4	21.4	3.7	51.5	4
11	48.6	51.2	.0	.2	N.d.
12	38.5	61.5	.0	.0	N.d.
13	43.2	56.8	.0	.0	N.d.
14	50.7	49.3	.0	.0	N.d.
15	22.7	21.9	27.4	28.0	N.d.
16	38.2	61.6	.2	.1	N.d.
17	15.0	12.8	51.8	20.4	N.d.
18	44.0	55.9	.1	.0	N.d.
19	43.2	56.8	.0	.0	N.d.
20	33.2	66.8	.0	.0	N.d.
21	24.2	61.0	14.8	.2	N.d.
22	23.6	53.1	23.3	.0	N.d.
23	19.4	70.4	10.1	.1	N.d.
24	24.9	67.1	7.9	.1	N.d.
25	25.0	63.9	11.1	.0	N.p.
26	45.7	54.3	.0	.0	N.d.
27	42.4	10.5	38.4	8.7	N.d.
28	1.4	17.4	60.7	20.5	4

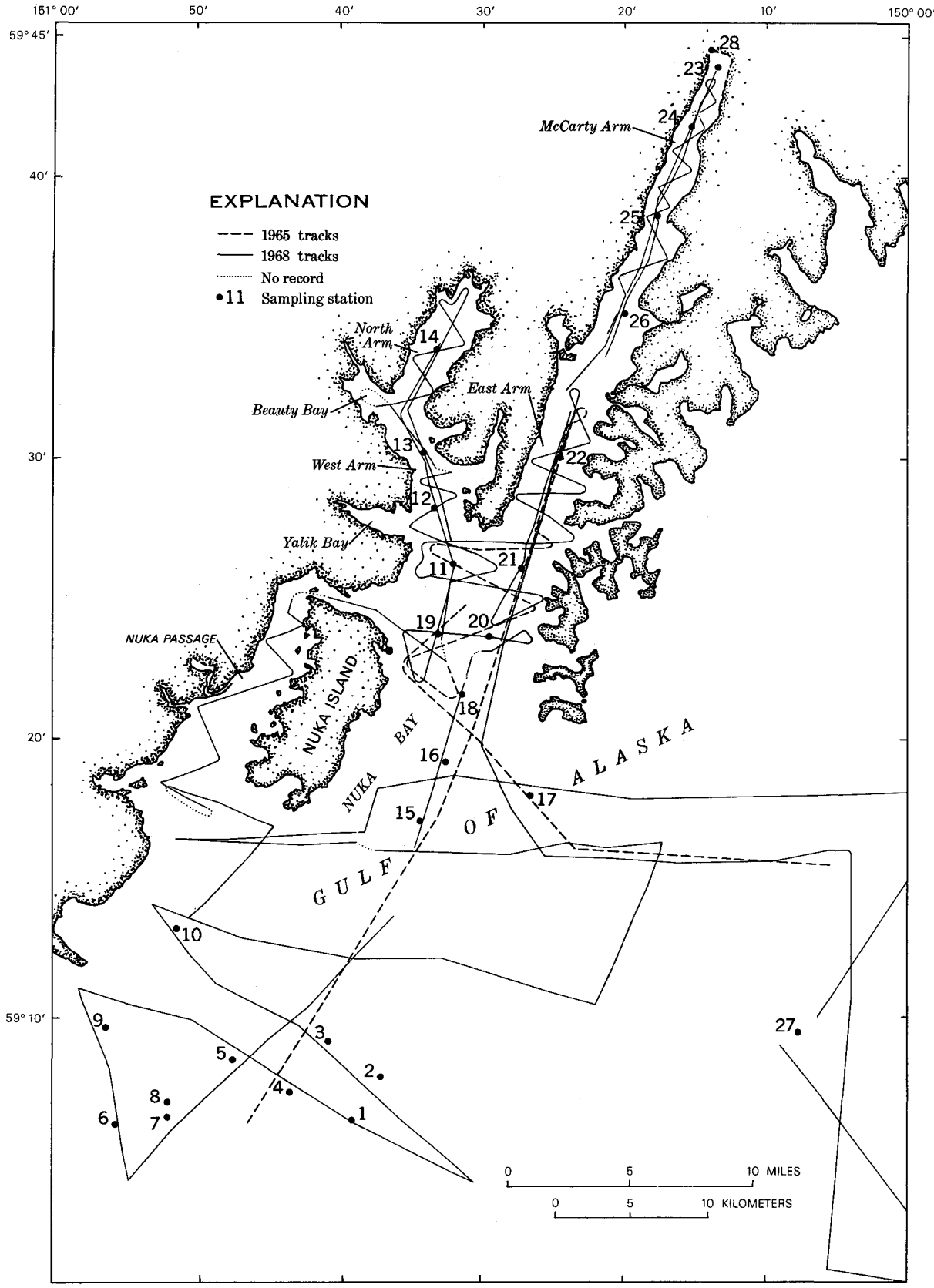

FIGURE 2.—Simultaneous arcer and fathometer transects and sample locations in Nuka Bay. Results of a 1965 survey included (von Huene, 1966).

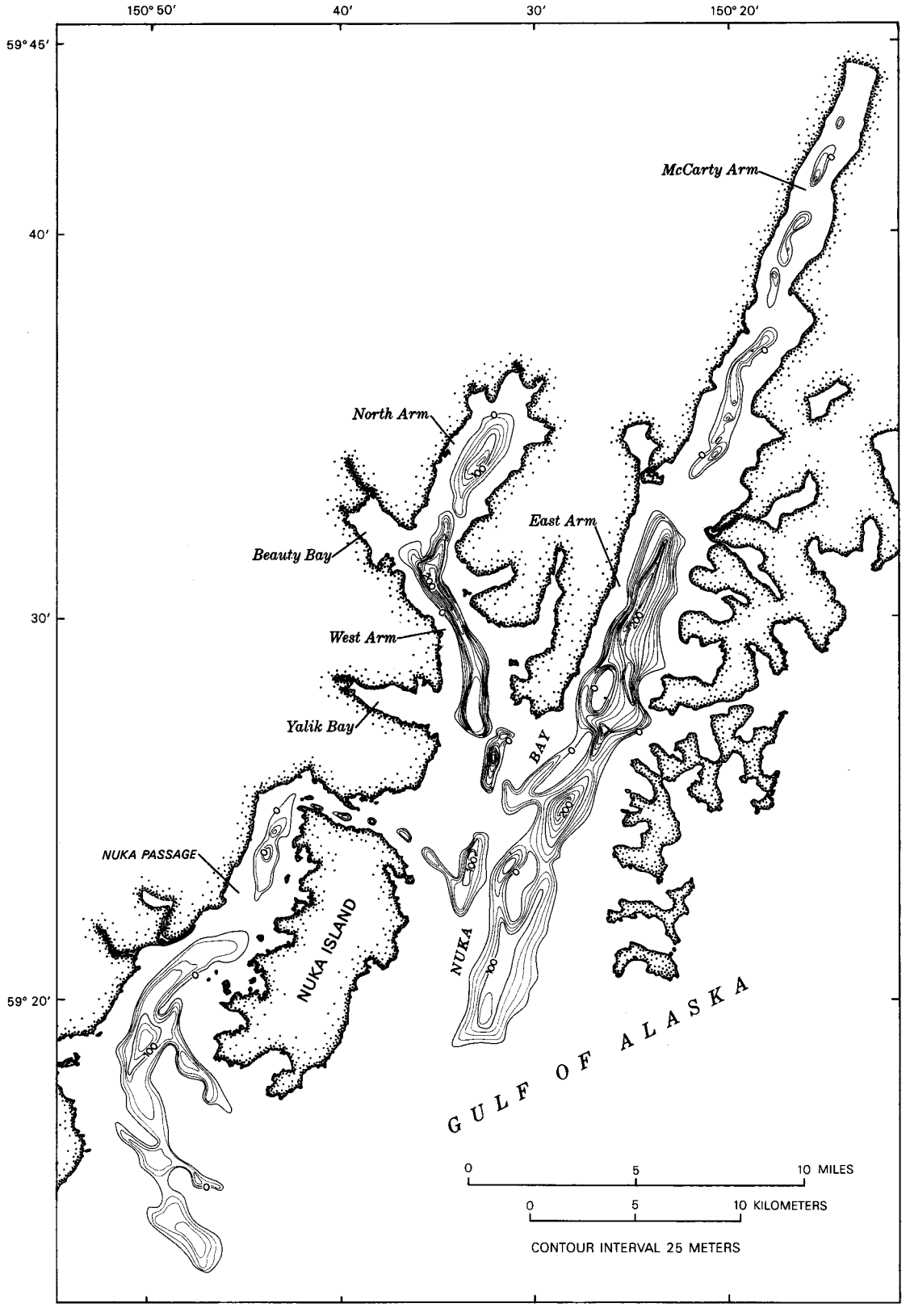

FIGURE 3.—Isopach map of stratified Holocene marine sediment in the bottom of Nuka Bay, Alaska, based on arcer profiles shown on figure 2 and a sediment sound velocity of 1,500 m/sec.

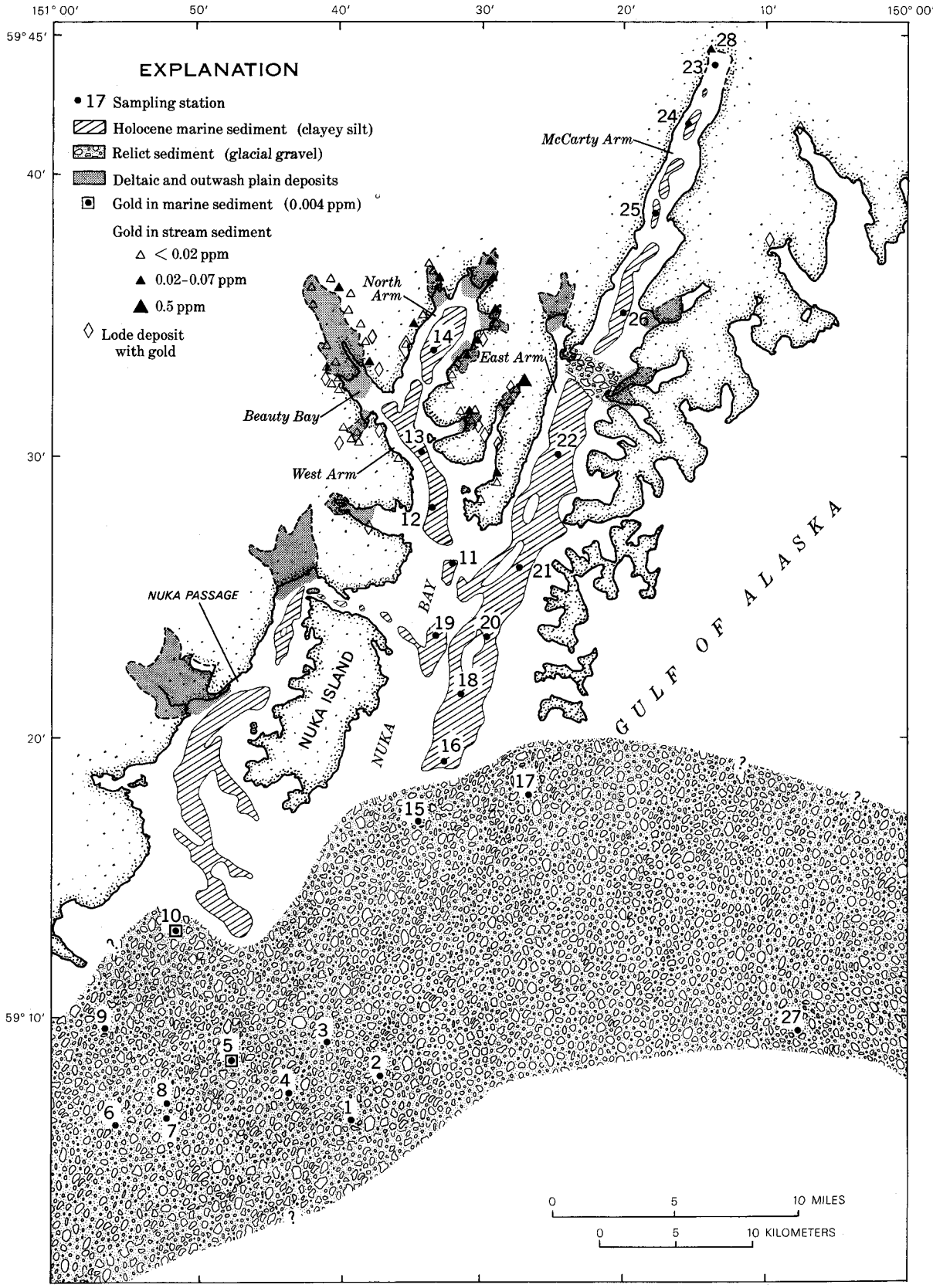

FIGURE 4.—Generalized sediment distribution in Nuka Bay as outlined on the basis of bottom samples and interpretation of arcer profiles. Gold in stream sediment from Richter (1968); gold in lode deposits from Cobb (1969).

layers in several cores occasionally show bedding which grades from coarser to finer upward. Some of these sandy layers are largely fragments of local rocks; others contain large percentages of volcanic glass. Ice rafting is not indicated except for an occasional isolated pebble, nor is there indication of cyclic phenomena suggestive of seasonal variations in sediment supply. The long, thin worm tubes and large-scale burrow structures that are numerous in some cores together with the light-gray to blue-gray sediment suggest that conditions on the fiord floors are not reducing.

GOLD ANALYSIS

The results of the gold analyses are given in table 1. A trace of gold was determined in only three of the 28 samples (fig. 4). Two of these are located in the area of relict glacial drift, the third at the terminus of McCarty Glacier. In the sample from station 5 the gold is in the 0.062–0.125-mm size fraction; in that from station 10, it is in the smaller than 0.062-mm fraction. In the sample from station 28, some gold occurs in the 0.125–0.250-mm size fraction, but it is mainly in the smaller than 0.062-mm fraction.

DISCUSSION

Holocene sediment accumulation in the Nuka Bay area has been restricted to the fiords for the most part. This agrees with observations made during an aerial reconnaissance of the region in July 1968, when the discolored fiord water was seen to extend onto the Continental Shelf for only a short distance.

The Holocene deposits within the bay can be broadly divided into two distinct types: a mud fraction (clayey silt), which lies in deep pockets on the fiord floors, and a sand and gravel fraction, which is retained in small deltas along the inner portions of the fiords and also makes up such distinct morainal features as the sill separating East Arm from McCarty Arm.

A number of seismic profiles show evidence of slumps at the foot of steep fiord walls and deltas. Slump features may result from mass movement of sediment, a common occurrence with steep foreset beds of fiord deltas. Slope failures occur during earthquakes but, in deltas, also during normal conditions of progradation (Coulter and Migliaccio, 1966). Such mass movements occasionally supply relatively coarse-grained material to the deep fiord floors, where it may remain in large masses or transform into turbidity currents that spread sediment in extensive, near-horizontal layers (Holtedahl, 1965). Certain sandy layers found in cores may represent such turbidities. The presence of sills between adjacent sediment pockets and the difference in the level of sediment fill in such pockets suggest that turbidity currents do not travel between individual pockets in Nuka Bay (von Huene, 1966).

Judging by the sparsity of ice-rafted debris in the cores, ice rafting at present is of little importance in the Nuka Bay area. This seems to be true even in McCarty Arm, where a tidal glacier is in retreat.

A slow rain of suspended matter from the overlying water seems to supply the bulk of material to the fiord bottom. The fine grain size of this material and the apparent absence of microrelief on the bottom suggest that tidal currents have no significant effects on the bottom. The presence of burrowing organisms in certain basins of the fiord floor suggests, however, that these basins are not stagnant.

Fine-grained sediment apparently is not being deposited on the open shelf today. The mud matrix in gravelly shelf sediment, therefore, seems to reflect a former environment of deposition by glaciers or by floating ice and suggests that this glacial sediment has not been reworked since the time of deposition.

Fourteen of the 28 sampling stations occupied in the Nuka Bay area lie within the pockets of Holocene marine sediment. None of these contains gold. Two of the three samples with a low gold concentration have been interpreted as representing glacial drift that in turn may be more or less representative of the country rock in general. The third sample with a low gold concentration is from a small delta at the snout of the retreating McCarty Glacier. Forty-four stream-sediment samples from areas surrounding North and West Arm have been analyzed for gold (Richter, 1968). In 12 of these samples, gold was detected with a concentration ranging from 20 to 500 parts per billion.

The distribution pattern and the occurrence of gold in the fine sand–coarse silt size fraction suggest that detrital gold supplied by the drainage basin stays in the coarse part of the total load. It therefore is incorporated into deltas. These fiord deltas are protected from marine reworking, thus making the chance for further concentration of the gold very small.

The bottom of Nuka Bay and other similar fiords does not seem to be a favorable environment for concentrating gold or other heavy metals. Significant concentrations of gold in soupy surface layers, apparently not incorporated into the fiord fill, have been reported from southeastern Alaska. Sampling techniques used in the present investigation were not suitable for proving or disproving the existence of such a soupy layer in Nuka Bay.

CONCLUSIONS

The deep, sheltered fiord environment is an efficient sediment trap for all clastic material supplied since the last major ice retreat, when, apparently, the various basins were for the most part cleaned to bedrock. Subsequent sediment accumulation was rapid, with little sorting. Any detrital gold supplied was incorporated into deltas, together with the coarser part of the load. In Nuka Bay, a lack of sedimentary microenvironments, where the rate of marine reworking would exceed the rate of sediment accumulation, makes the possibility of the occurrence of an economic gold concentration unlikely.

A possible exception to the generalization of low potential gold content is a series of small sediment pockets detected in seismic records of the relatively shallow connection between Nuka Passage and East Arm. In view of strong currents and shallow depths in this area, the sediment accumulated may be coarser grained than that in the deeper basins and therefore may warrant additional sampling.

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A CORUNDUM OCCURRENCE IN THE EASTERN ALASKA RANGE, ALASKA

By DONALD H. RICHTER, Anchorage, Alaska

Abstract.—Crystals of gray corundum, as much as 8 cm long, occur in alkali pegmatite dikes in the Mentasta Mountains of the eastern Alaska Range. The pegmatite dikes cut a syenite-monzonite gneiss that is part of a large metaigneous complex consisting principally of diorite and diorite gneiss. Field relations and K-Ar dates suggest that the rocks of the complex were syntectonically emplaced during late Permian or Triassic time. The pegmatite dikes are composed almost entirely of orthoclase, orthoclase microperthite, and soda feldspar; biotite and hornblende are minor constituents. Corundum has only been recognized in three dikes and where present is generally associated with muscovite. Asteriated stones have been cut from the larger corundum crystals, but the poor quality and scarcity of the crystals preclude an economic gem industry.

In 1964, Mr. Ray Gatz, an Alaskan prospector, brought news of an occurrence of blue sapphire in the Mentasta Mountains of the eastern Alaska Range. The area was visited briefly by the author in 1967 and 1968, but it was not until the summer of 1969 that the author's U.S. Geological Survey field party examined the area in more detail.

Scattered fragments of claim posts(?) and an old weathered sieve in the vicinity of the corundum deposits indicate that Gatz had rediscovered a locality that had been prospected probably prior to and during the early part of World War II when a nearby molybdenum deposit was being explored (Moffit, 1954, p. 209). The occurrence may also have been known much earlier and perhaps was the source of an ambiguous report by Kunz (1899, p. 520), who mentioned seeing "good grey and pink specimens of asteriated corundum from a locality on the Copper River in the Juneau Indian Reservation [sic], Alaska." Kunz' report was referred to in a description of corundum deposits in the United States (Pratt, 1901, p. 88), but since then no mention of corundum in Alaska has appeared in the literature.

The corundum occurs in thin pegmatite dikes that cut a syenite-monzonite gneiss, and although probably of value only as a mineralogical curiosity, its uniqueness and geologic setting warrant description.

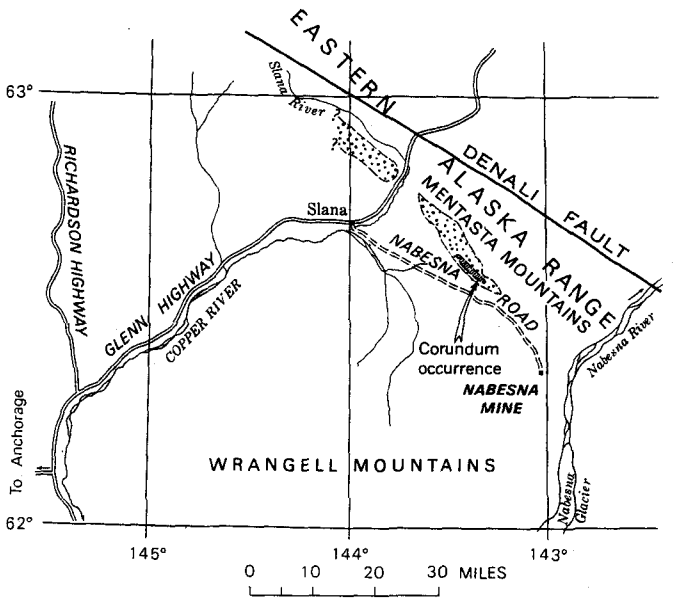
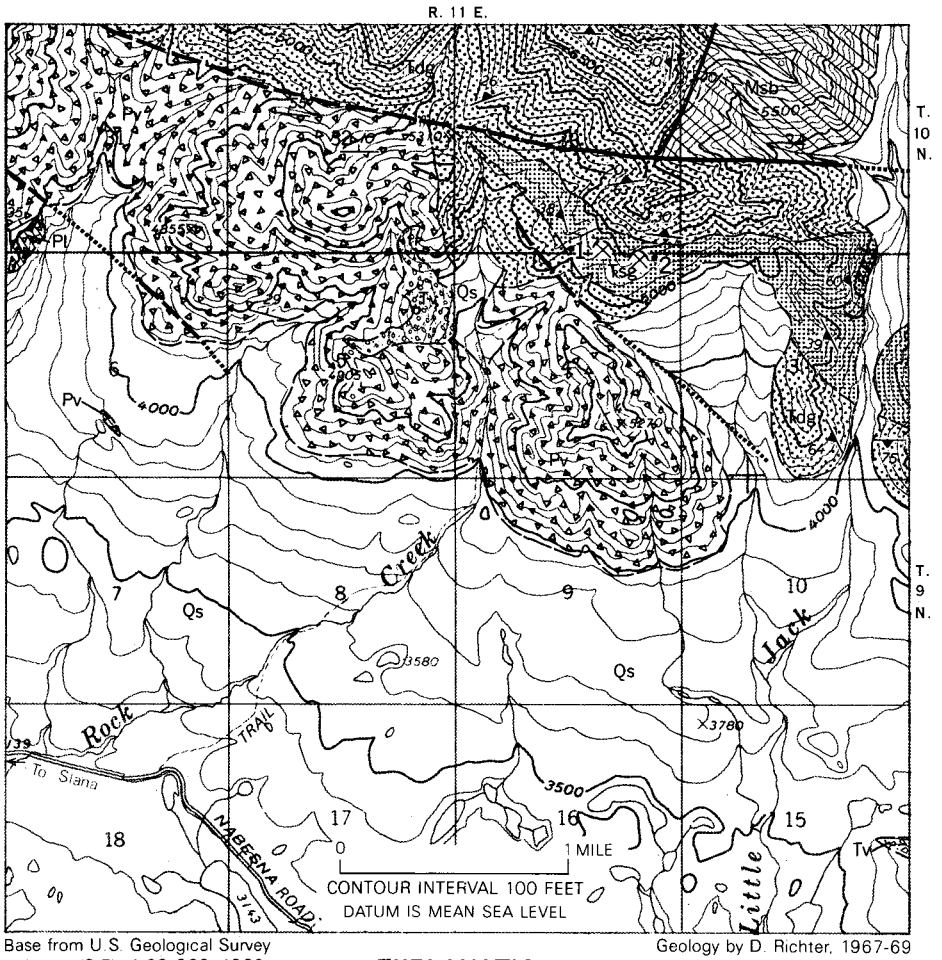


FIGURE 1.—Sketch map of a part of south-central Alaska, cipal geologic features. Ruled area shows zone of syenite-monzonite gneiss within metaigneous complex (stippled).

LOCATION AND ACCESSIBILITY

The known corundum-bearing pegmatites are restricted to a ¼-mile-square area at an elevation of between 5,300 and 5,500 feet on the southern flank of the Mentasta Mountains in the eastern Alaska Range (figs. 1 and 2). The area is within the Nabesna C–5 quadrangle (scale 1:63,360), and the map coordinates are lat 62°36′ N. and long 143°21′ W.

The area is easily accessible from the Nebesna Road, an intermittently maintained gravel road that leaves the Glenn Highway at the small community of Slana about 263 miles northeast of Anchorage (fig. 1). Approximately 20 miles east of Slana on the Nabesna Road, an old trail a little over 3 miles long leads to an adit at an abandoned molybdenite prospect, which is a few hundred feet west of the westernmost corundum occurrence (fig. 2).



Base from U.S. Geological Survey Nabesna (C-5), 1:63,360, 1960

Geology by D. Richter, 1967-69 and N. Matson, Jr., 1969

EXPLANATION

SEDIMENTARY AND VOLCANIC ROCKS

QUATERNARY

Qs — Unconsolidated deposits

TERTIARY

Tv — Volcanic rocks; may include related intrusive rocks

CRETACEOUS JURASSIC TRIASSIC

Msb — Argillite, limestone, and amygdaloidal basalt

PERMIAN

Pv, Pl — Volcanic and volcaniclastic rocks with minor limestone (Pl)

TRUE NORTH — MAGNETIC NORTH (29½°)

APPROXIMATE MEAN DECLINATION, 1970

METAMORPHIC ROCKS

TRIASSIC(?)

kdg — Chiefly diorite gneiss

ksg — Chiefly syenite and monzonite gneiss

Approximate contact

Fault
Dashed where inferred; dotted where covered

35 — Strike and dip of beds

30 — Strike and dip of foliation

Adit
Molybdenite prospect

Corundum-bearing alkali pegmatites

•1 — Rock-sample locality referred to in text

FIGURE 2.—Geologic map of the corundum-bearing area, Mentasta Mountains, eastern Alaska Range, Alaska.

GEOLOGIC SETTING

The host rock for the corundum-bearing pegmatites is a unique peraluminous syenite-monzonite gneiss that is part of a large metaigneous complex consisting principally of diorite gneiss and a variety of nonfoliated diorites with subordinate amphibolite, metagabbro, and schistose cataclasite. Most of the alkali gneisses, including those that are host to the alkali pegmatites, are confined to a well-defined zone approximately 6 miles long and as much as 1 mile wide in the extreme southeastern end of the metaigneous complex (fig. 1). The contact between the alkali gneiss zone and the enclosing diorite gneiss is broadly gradational. A few layers of diorite gneiss occur within the alkali gneiss zone, and thin layers of alkali gneiss are scattered throughout much of the complex but appear to be especially common near the alkali gneiss zone.

Gneissic banding, foliation, and lineation directions within the metaigneous complex trend generally northwest, parallel to the major structural features of the eastern Alaska Range. Foliation dips are steep and generally to the northeast, but anomalous reversals indicate strong local folding.

Although the gneissosity displayed by much of the rock in the complex indicates high-grade regional metamorphism, the common mineral assemblage of horn-blende-biotite-plagioclase (-quartz-alkali feldspar-epidote) in the diorite gneisses suggests a metamorphic environment no higher than the greenschist facies. Local schistose cataclasites containing the assemblage quartz - muscovite - plagioclase-almandine-potassium feldspar provide evidence of strong dislocation metamorphism. All rocks show the effects of retrograde metamorphism by the development of chlorite after biotite and hornblende.

The metaigneous complex, although predominantly fault bounded, locally appears to exhibit gradational intrusive relations with a thick unit of andesite volcanics and volcaniclastics of Permian age. These apparent intrusive contacts consist of a complex metamorphic and dioritized aureole as much as a mile wide. The rocks within the aureole are principally albite-epidote to hornblende hornfels with irregular segregations of both normal and foliated diorite.

K–Ar dating of coexisting hornblende and biotite from an alkali pegmatite in the alkali gneiss at the molybdenite prospect (fig. 2) indicates concordant ages of 199 and 198 m.y., respectively, for the minerals. The alkali pegmatites probably represent an extremely late stage of igneous activity within the complex; thus, the K–Ar dates indicate that emplacement of the complex probably culminated in late Triassic time. The intimate association of normal igneous rocks, metamorphic rocks, and cataclasites further suggests that emplacement occurred during a prolonged and complex tectonic event in an ancestral Alaska Range.

The syenite-monzonite gneisses are light pink and contrast boldly with the dark-gray diorite gneisses. Gneissosity in the syenites and monzonites is characterized by biotite- and (or) hornblende-rich layers alternating with feldspathic bands poor in mafic minerals. Thicknesses of the layers range from less than a tenth of an inch to more than a foot; the mafic layers are conspicuously thinner and less continuous than the feldspathic layers. The syenite gneisses and monzonite gneisses are indistinguishable in hand specimen, and even in thin section more than cursory examination is necessary to differentiate the two types. Apparently, changes in the potassium feldspar to plagioclase ratio are subtle and may occur even within single bands over relatively short distances. The alkali gneisses exhibit a typical xenoblastic texture; very few individual crystals are more than 2 mm in diameter. Locally, the rocks are porphyroblastic, with porphyroblasts of microperthite as much as 30 mm long. Some of the larger feldspar porphyroblasts and most of the late accessory minerals including the corundum are poikiloblastic.

In most places, the alkali gneisses have a low color index and consist principally of potassium feldspar and albite-oligoclase and minor biotite and hornblende. Accessory minerals are muscovite, corundum, sphene, zircon, opaque minerals, zoisite, and carbonate. Modal analyses of the syenite and monzonite gneiss and a diorite gneiss occurring within the alkali gneiss are listed in table 1. Most of the potassium feldspar in the gneisses is orthoclase or orthoclase microperthite. The large porphyroblasts in the porphyroblastic variants, however, are apparently microcline microperthites that have undergone some rotation. Not all the soda feldspars exhibit multiple twinning, and where twinning is absent, they are difficult to distinguish from orthoclase unless stained. In general, both feldspars are fresh, although locally the plagioclase is saussuritized. Both brown and green biotite are present in the gneisses, but the green variety predominates. Both also show alteration to chlorite. Corundum is present in all sections examined and occurs as small (<0.5 mm) euhedral crystals. Euhedral crystals of sphene, typically diamond shaped in cross section and as much as 1 mm long, are locally abundant in some of the gneisses, especially in the mafic-rich bands. The opaque minerals are probably magnetite or magnetite-ilmenite mixtures and are generally associated with white opaque leucoxene. Carbonate minerals and zoisite occur as small irregular aggregates scattered through the gneiss.

TABLE 1.—*Modal analyses of alkali gneisses and related rocks, Mentasta Mountains, eastern Alaska Range, Alaska*

[Tr., trace]

Field No.	67-ARh-172	68-ARh-325	69-ARh-1	69-ARh-2	69-ARh-3b
Rock name	Monzonite gneiss	Syenite gneiss	Syenite gneiss	Porphyroblastic monzonite gneiss	Diorite gneiss
Potassium feldspar.	45	65	61	[1] 43	--------
Plagioclase	45 (An_{10})	26 (An_{8-10})	31	48 (An_{10-14})	30 (An_{46-55})
Biotite [2]	5	1	4	3	--------
Hornblende	----------	3	----------	----------	59
Clinopyroxene	----------	----------	----------	----------	5
Muscovite	1	----------	----------	----------	2
Zoisite	----------	----------	3	5	--------
Corundum	1	Tr.	Tr.	Tr.	--------
Sphene	1	2	--------	1	--------
Zircon	Tr.	--------	Tr.	Tr.	--------
Carbonate	Tr.	----------	----------	----------	----------
Opaque minerals	2	3	1	Tr.	4

Location of samples:
67-ARh-172: Elevation 4,600 feet, 1.6 miles S. 65° E. of loc. 2, figure 2.
68-ARh-325: Elevation 5,500 feet, 2.8 miles N. 55° W. of loc. 2, figure 2.
69-ARh-1, 69-ARh-2: Elevation 5,020 feet, loc. 1, figure 2.
69-ARh-3b: Elevation 5,400 feet, loc. 2, figure 2.

[1] Includes microcline microperthite porphyroblasts (26 percent) and matrix orthoclase (17 percent).
[2] Predominantly green biotite locally altered to chlorite.

GEOLOGY AND MINERALOGY OF THE CORUNDUM-BEARING PEGMATITES

Pink, coarse-grained to pegmatitic syenite dikes are relatively common throughout the alkali gneiss zone in the complex, but only in one small area are they known to contain corundum crystals of any size. The dikes are small and discontinuous; most are less than 3 feet wide. They are massive and exhibit clear, distinct crosscutting relations with the host gneiss; however, the actual contact may be either sharp or gradational. The easternmost corundum-bearing dike cuts a fine-grained schistose rock less than 1 foot thick consisting of epidote, white mica, plagioclase, and carbonate with veinlets of fibrous calcite and fresh andesine. Crystals are as large as 10 to 15 cm in the dike rocks, but the average grain size is 3 cm or less. Commonly a matrix of medium-grained crystals is present. The mineralogy of the dikes is simple, with orthoclase, orthoclase microperthite, and soda feldspar the principal constituents. Antiperthite, consisting of soda feldspar with streaky blebs of potassium feldspar, was observed in one thin section. Small crystals of dark-green biotite are common minor constituents. Locally, dark massive hornblende is present, but the mafic minerals do not constitute more than 2 percent by volume of the dikes at any locality. Sporadic aggregates or groups of gray corundum crystals occur in at least three of the dikes at the localities shown in figure 2. Small books of light-gray to very pale grayish-lavender muscovite as large as 3 cm in diameter are generally associated with the corundum. The muscovite is a dioctahedral mica; it does not have an unusually high lithium content, contrary to what its color suggests. The trace-element chemistry of the pegmatites is also comparatively simple, as indicated by a spectrographic analysis of bulk material from one of the corundum-bearing localities (table 2). Neither the rare earth elements nor the other elements commonly found in alkali rocks, such as Mo, Be, W, Zr, and Nb, are present in amounts exceeding the average crustal abundance.

The corundum crystals occur as elongate, doubly terminated hexagonal pyramids as much as 2 to 8 cm long and 2 to 3 cm in diameter (fig. 3). Many of the

TABLE 2.—*Semiquantitative spectrographic analysis of corundum-bearing alkali pegmatite, Mentasta Mountains, eastern Alaska Range, Alaska*

[Looked for, but not detected: P, Ag, As, Au, Cd, Co, Cr, Ge, Hf, Hg, In, Li, Mo, Ni, Pd, Pt, Re, Sb, Sc, Sn, Ta, Te, Th, Tl, U, V, W, Yb, Zn, Pr, Nd, Sm, and Eu. Analyst: Chris Heropoulos]

Element	Content (weight percent) [1]	Element	Content (weight percent) [1]
Si	10	Be	.00015
Al	10	Ce	.01
Fe	.5	Cu	.0005
Mg	.15	Ga	.002
Ca	.5	La	.005
Na	3.0	Nb	.005
K	3.0	Pb	.002
Ti	.07	Sr	.007
Mn	.01	Y	.001
B	.002	Zr	.005
Ba	0.02		

[1] Results are reported in percent to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15 and 0.1, and so forth, which represent approximate midpoints of interval data on a geometric scale. The assigned interval for semiquantitative results will include the quantitative value about 30 percent of the time.

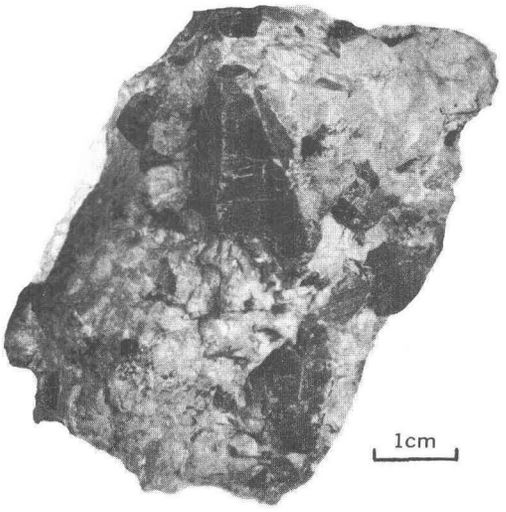


FIGURE 3.—Corundum crystals in alkali pegmatite (sample 69-ARh-3).

crystals are bent or badly misshapen. Inclusions of feldspar are common, and a thin microselvage of fine-grained white mica generally coats the outside of a crystal. Most of the crystals are badly fractured, breaking along the perfect basal parting (0001), and are difficult to remove whole from the pegmatite matrix. Although gray when fresh, the corundum becomes bluish gray after exposure to sunlight.

Since the original discovery of the corundum, prospectors and miners have optimistically viewed the deposits as a source of gem sapphire. Within the last 2 years, Mr. Robert McGrane, an Anchorage jeweler, has cut cabochons from some of the weathered corundum, producing attractive blue-gray stones that generally show asterism. However, the badly fractured habit of the crystals, the abundance of feldspar inclusions, the poor color in fresh material, and the overall paucity of crystals preclude the development of an economic gem enterprise.

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AGE AND STRATIGRAPHY OF THE HECETA LIMESTONE IN NORTHERN SEA OTTER SOUND, SOUTHEASTERN ALASKA

By A. T. OVENSHINE and G. D. WEBSTER,[1]
Menlo Park, Calif., Pullman, Wash.

Abstract.—The Heceta Limestone in the northern Sea Otter Sound area, Alaska, is more than 10,000 feet thick and contains two major zones of terrigenous clastic rocks. On the basis of sparse conodonts, graptolites, and bachiopods, it is late Early through Late Silurian in age. This new age assessment of the formation requires extension of the range in southeastern Alaska of the stromatoporoid *Amphipora* and the pelecypod *Pycinodesma*, both previously considered no older than Middle Devonian.

The Heceta Limestone (Eberlein and Churkin, 1970) is 10,000 to 16,000 feet thick, consists mainly of limestone and conglomerate, and is widely distributed in the southern parts of southeastern Alaska. The clastic wedge of the Karheen Formation (Eberlein and Churkin, 1970; Ovenshine and others, 1969) above it, and the unconformity below it, record significant early Paleozoic tectonic events; thus it is useful to know the time span represented by the Heceta Limestone. The purpose of this paper is to present paleontological evidence that the limestone is late Early through Late Silurian in age.

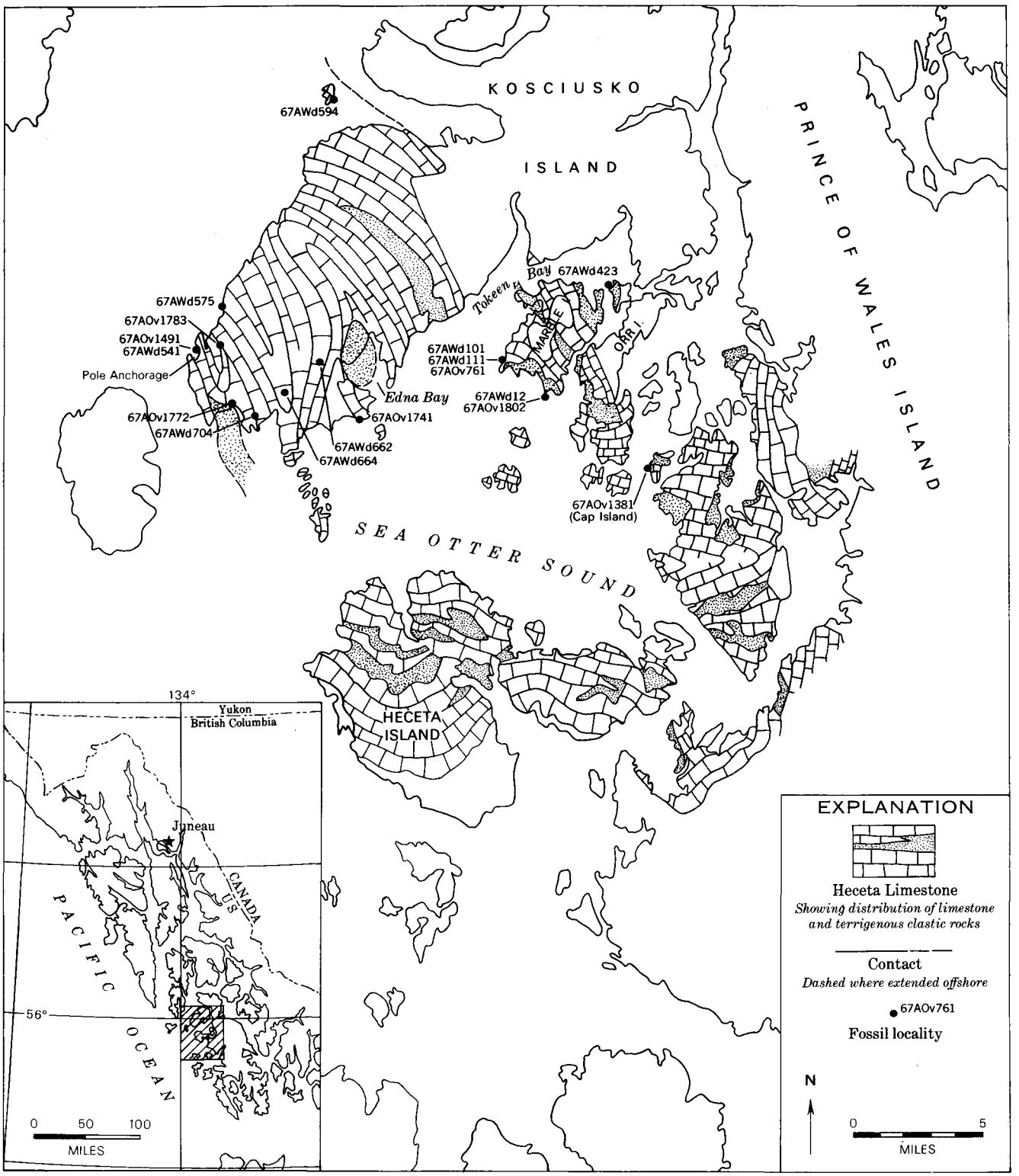
Acknowledgments.—The writers identified the conodont elements but wish to acknowledge helpful comments by Gilbert Klapper, of the University of Iowa. Dr. Klapper also advised us on the stratigraphic position of the *amorphognathoides*-Zone fauna. Dr. J. G. Johnson, of Oregon State University, kindly identified brachiopods from Marble Island and suggested their stratigraphic range. Claire Carter and Michael Churkin, Jr., of the U.S. Geological Survey, identified the graptolites found in the Heceta Limestone. The use made of this information is the responsibility of the writers.

HECETA LIMESTONE

Limestone, conglomerate, sandstone, and shale of the Heceta Limestone are well exposed around Sea Otter Sound in the northwest coastal area of Prince of Wales Island, Alaska (fig. 1). The area where we have mapped and studied the formation is indicated by the fossil localities in figure 1; in the southern part of Sea Otter Sound the formation has been investigated by G. D. Eberlein. The contact between the Heceta Limestone and the underlying Descon Formation of Early Ordovician through Early Silurian age (Eberlein and Churkin, 1970) is an angular unconformity at both Cap Island (locality 67AOv1381 in fig. 1) and east of Tokeen Bay (locality 67AWd423 in fig. 1). Basal conglomerates less than 300 feet thick are present at both localities and consist of rounded megaclasts of gray chert, red chert, and limestone from an unknown source, as well as angular fragments of basalt, argillite, and graywacke derived from the underlying Descon Formation. The upper contact of the Heceta Limestone with the Karheen Formation (Eberlein and Churkin, 1970) is conformable where exposed on Kosciusko Island (locality 67AOv1741).

Figure 2 portrays gross lithic aspects of the Heceta Limestone and also shows some of the subdivisions that have been recognized in the geologic mapping of the northern Sea Otter Sound area. About half of the formation is limestone, the most common variety of which is very light gray and finely crystalline. The limestone generally lacks bedding and primary texture. Acetic acid insoluble residues amount to less than 1 percent of sample weight and consist principally of 0.25-mm dolomite rhombs. Fossils other than dasycladacean algae are very rare. That the original nature of much of this limestone may have been a coarse breccia is suggested by the presence of this texture in places such as beneath the water of some tidepools, areas where fires have baked outcrops, and weathered surfaces beneath the roots of recently fallen trees. Strongly contrasting with the light-colored massive limestone is the dark-gray bedded limestone locally present in the for-

[1] Washington State University, Pullman, Wash.



Geology modified from unpublished mapping by G.D. Eberlein, 1947–49; Eberlein and M. Churkin, 1965–66; and A.T. Ovenshine and G.D. Webster, 1967

FIGURE 1.—Distribution of the Heceta Limestone in the Sea Otter Sound area, and locations of fossil collections discussed in this report.

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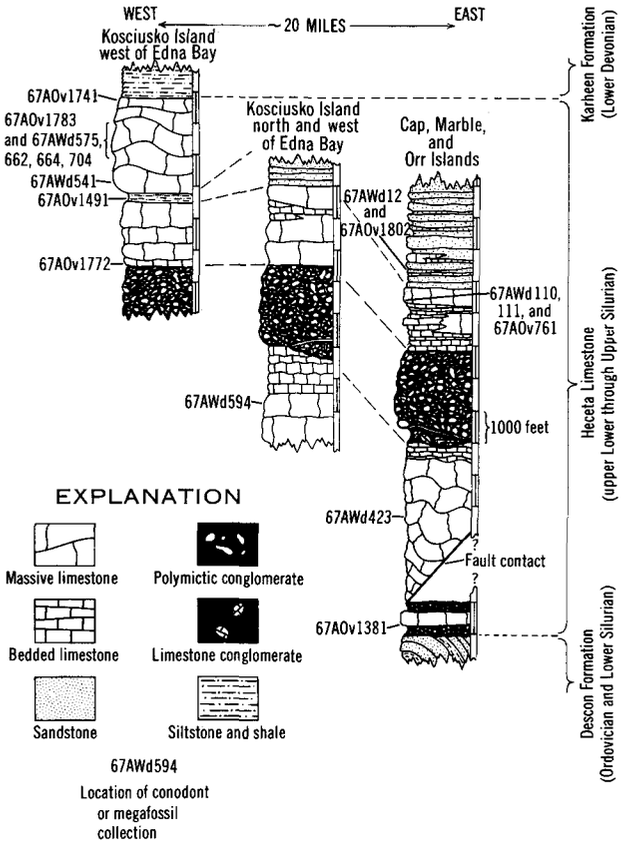

FIGURE 2.—Stratigraphy of the Heceta Limestone in northern Sea Otter Sound, southeastern Alaska.

mation, particularly above or below terrigenous clastic strata. The bedded limestone, which is commonly argillaceous biomicrite and less commonly argillaceous biopelmicrite, in places contains abundant stromatoporoids, corals, and gastropods and less commonly brachiopods, pelecypods, crinoids, and conodonts. The bedded limestone yields insoluble residues that may amount to several percent of sample weight and consist chiefly of carbonaceous matter, pyrite, and dolomite. Rare limestone varieties in bedded zones are crinoidal, pelletoidal, and oolitic limestones and roundstone and edgewise conglomerate.

In the northern Sea Otter Sound area there are two thick zones of terrigenous clastic rocks within the Heceta Limestone. The lower zone, which is about 2,500 feet thick, is dominantly coarse conglomerate in which the subrounded pebble- to boulder-sized megaclasts of andesite, red and gray chert, limestone, and graywacke greatly predominate over pebbles of gabbroic to granitic plutonic rock and milky quartz. The megaclast fraction is moderately closely packed and moderately sorted so that bedding is well expressed; the matrix is calcareous lithic graywacke. The base of the lower clastic zone on Marble and Orr Islands and the eastern part of Kosciusko Island is a disconformity overlain by 50 to 300 feet of monomictic conglomerate consisting of rounded limestone megaclasts closely packed in a tan limestone matrix.

The upper clastic zone is well exposed at the south end of Marble Island where it consists of more than 3,000 feet of lithic graywacke (shown by sandstone pattern in fig. 2) and minor argillaceous limestone. This graywacke unit thins westward rapidly; on western Kosciusko Island (near locality 67AOv1491) it is represented by only a few hundred feet of black shale and arenaceous limestone. The lower contact of the graywacke is gradational with the underlying limestone on Marble Island.

PALEONTOLOGIC DATA

Conodonts

Limestone samples averaging 0.8 kilogram in weight were digested in 10-percent acetic acid; the heavy portions of the residues were isolated by 2.85-bromoform separation and searched for conodonts. Approximately two-thirds of the 100 samples yielded from one to five specimens, but most contained only distacodontid conodont elements. Fifteen samples yielded compound conodonts, and for these, locality numbers and forms identified are listed in table 1. Localities of conodonts and other fossils are also shown on the map in figure 1 and on the stratigraphic sections of figure 2. Of the 15 compound conodont faunas, 3 contains from 25 to 200 specimens. These three are discussed in the following paragraphs.

Sample 67AOv1381 is from the base of the Heceta Limestone on Cap Island and contains the zone fossil and other elements of the *Pterosphathodus amorphognathoides* Zone recognized in the Silurian of Europe by Walliser (1964). Walliser regarded the *P. amorphognathoides* Zone as of late Llandoverian and early Wenlockin age. Gilbert Klapper (oral commun., 1968) believes that the *P. amorphognathoides* Zone is entirely within the late Llandoverian. Accepting Klapper's age assessment, we consider the base of the Heceta Limestone on Cap Island to be of late Early Silurian age. Eberlein and Churkin (1970) report graptolites of late Early or early Middle Silurian age 1,500 feet below the base of the Heceta in its type area. They correlated the base of the Heceta approximately with the Lower-Middle Silurian boundary.

Samples 67AWd111 and 67AWd101 are from limestone within the middle part of the Heceta and yield conodont species, most of which have known ranges from Silurian to early Devonian (Walliser, 1964, table 1). The presence of *Polygnathoides emarginatus*, which

TABLE 1.—*Conodonts from the Heceta Limestone*

Conodont	Locality number															Age
	67AWd12	67AWd101	67AWd111	67AWd423	67AWd541	67AWd575	67AWd594	67AWd662	67AWd664	67AWd704	67AOv1381	67AOv1491	67AOv1741	67AOv1772	67AOv1783	
Belodella resima	----	----	----	----	----	X	----	X	X	----	----	----	X	----	----	Ludlow (Upper Silurian)
triangularis	----	----	----	----	----	----	----	X	----	----	----	----	----	----	----	
Hindeodella equidentata	X	----	X	----	----	----	X	----	X	X	----	----	----	X	----	
? *Lonchodina* sp	----	----	----	----	X	----	----	----	----	----	----	----	X	----	----	
Neoprioniodus excavata	----	----	----	----	X	----	X	----	X	----	----	----	----	X	----	
Ozarkodina sp. aff. *edithae*	----	----	----	----	----	----	----	----	X	----	----	----	----	X	----	
media	X	----	X	X	----	----	X	----	X	----	----	----	----	----	----	
Plectospathodus extensus	X	----	X	----	X	----	----	----	X	----	----	----	----	----	----	
Polygnathoides emargina	----	X	----	----	----	----	----	----	----	----	----	----	----	----	----	
Spathognathodus inclinatus	X	----	X	X	----	----	----	----	X	----	----	X	----	X	----	
Trichonodella excavata	----	----	X	X	----	----	----	----	X	----	----	----	----	----	----	
T. sp. aff. *inconstans*	----	----	----	----	X	----	----	----	----	----	----	----	----	----	X	
Neoprioniodus planus	----	----	----	----	----	----	----	----	----	----	X	----	----	----	----	*Amorphognathoides* Zone (Uppermost Lower Silurian)
Ozarkodina sp. aff. *gaertneri*	----	----	----	----	----	----	----	----	----	----	X	----	----	----	----	
Pterospathodus amorphognathoides	----	----	----	----	----	----	----	----	----	----	X	----	----	----	----	
Roundya trichonodelloides	----	----	----	----	----	----	----	----	----	----	X	----	----	----	----	
Scolopodus sp	----	----	----	----	----	----	----	----	----	----	X	----	----	----	----	
Trichonodella brassfieldensis	----	----	----	----	----	----	----	----	----	----	X	----	----	----	----	

in Europe is found only in the upper *crassa* to *siluricus* Zones (Walliser, 1964, p. 66), implies a lower to middle Ludlow age. The samples are from the same beds that yielded the brachiopod fauna discussed later under locality 67AOv761.

Sample 67AWd664 is from massive limestone approximately 1,500 feet below the red and green shales which are stratigraphically above the Heceta Limestone in the Kosciusko Island area. Conodont species from this sample all have known ranges from Late Silurian to Early Devonian (Walliser, 1964, table 1). The composition and general aspect of the conodont fauna, however, suggest a correlation with conodonts from the Ludlovian Aymestry Limestone of England (Rhodes, 1953). In particular, *Spathognathodus inclinatus* (sensu Rhodes non Walliser) shows close correspondence. Moreover, lacking are typical Lower Devonian conodont elements like those recovered from the overlying Karheen Formation. For these reasons, the horizon of 67AWd664 is considered as late Silurian in age, equivalent to that of the Aymestry Limestone.

Graptolites

Graptolites have been found in dark-gray silty limestone at two places at approximately the same stratigraphic position within the Heceta Limestone. Approximately 30 specimens were found at locality 67AOv1491 at Pole Anchorage on western Kosciusko Island, and 2 specimens were found at locality 67AOv1802 on a small island near the south end of Marble Island. These graptolites have been examined by Michael Churkin, Jr., and Claire Carter, of the U.S. Geological Survey, who state (oral commun., 1968) that the graptolites are *Monograptus* sp. indet. Churkin and Carter note that all the poorly preserved specimens probably represent a single species of a small monograptid with straight, simple thecae. But because of the poor preservation of the graptolites and because of the difficulty in assigning a precise age on the basis of a single monograptid species, refinement in age beyond Late Silurian is unwarranted.

Brachiopods

An abundant, well-preserved brachiopod fauna (67AOv761) found in dark-gray limestone a few hundred feet stratigraphically below the *Monograptus* sp. horizon on Marble Island has been examined by J. G. Johnson, of Oregon State University. Johnson (written commun., June 25, 1968) identifies:

Atrypella sp. (lenticular)
Atrypella carinata
Gracianella sp. aff. *umbra*
Hedeina sp. aff. *balchaschensis*
Rhynchotrema? sp.

Johnson states:

> All of these brachiopods except the questionable *Rhynchotrema* occur in the Ludlow interval of the Roberts Mountains Formation in the Roberts Mountains in beds that are well dated by the brachiopods, conodonts, and graptolites. However, I can't say for sure what part of the Ludlow is indicated.

The brachiopods of locality 67AOv761 are from the same beds that yielded the Ludlow-age conodont fauna of samples 67AWd111 and 67AWd101.

AGE OF THE HECETA LIMESTONE

The *amorphognathoides*-Zone conodont fauna from near the base of the Heceta Limestone (67AOv1381) on

Cap Island indicates the onset of limestone deposition no later than late Early Silurian time. Ludlow-age brachiopods and conodonts beneath the upper clastic zone and the graptolites from the basal part of the clastic zone indicate that the lower approximately 9,000 feet of the formation is no younger than Late Silurian. The uppermost important conodant fauna (67AWd-664), which comes from a horizon no more than 1,500 feet below the top of the formation, also suggests a Silurian age at least as high as this stratigraphic level. Thus, only the upper 1,500 feet of the formation could contain deposits of Devonian age. In the Heceta-Tuxekan Islands area, the lowest known Devonian fossils are approximately 1,400 feet above the base of the overlying Karheen Formation (Eberlein and Churkin, 1970), or approximately 3,000 feet above the horizon of 67AWd664.

RANGES OF AMPHIPORA AND PYCINODESMA

The consistent results provided by the study of conodonts, graptolites, and brachiopods are not mirrored in the results obtained from other fossil groups. In particular, corals, stromatoporoids, and mollusks, the more common fossils in the Heceta Limestone, have yielded inconclusive or conflicting results. Two that have been most vexing are discussed in the following paragraphs.

The small, tubelike stromatoporoid *Amphipora* and the large, thick-shelled pelecypod *Pycinodesma* are locally abundant in bedded limestone throughout the Heceta. Both have been used as guide fossils to the Middle or early Late Devonian in southeastern Alaska and elsewhere (Loney and others, 1963, p. C17).

Amphipora has been recognized in Devonian rocks in Europe and North America, and in southeastern Alaska it has been found in the Kennel Creek Limestone of Freshwater Bay, Chicagof Island, by Loney, Condon, and Dutro (1963, p. C17). These writers note:

> *Amphipora* is extremely common in rocks of Middle and early Late Devonian age throughout the Western United States, Canada, and in other parts of Alaska. This stromatoporoid genus has been recorded from the Silurian of Russia, but the faunal evidence supporting this age assignment is either absent or inconclusive.

Amphipora occurs in the Heceta Limestone at many places below the upper clastic zone; thus its range into the Silurian should be accepted for southeastern Alaska.

Kirk's (1927) assignment of a Late Silurian age to *Pycinodesma* was questioned by Loney, Condon, and Dutro (1963, p. C17). Eberlein and Churkin (1970) noted that *Pycinodesma* is present in the upper part of the Heceta Limestone and also in the Devonian Wadleigh Limestone. We have found *Pycinodesma* in association with *Amphipora* and the brachiopod *Conchidium* in parts of the Heceta Limestone well below the upper clastic zone. Thus, the range of *Pycinodesma* into the Silurian, as Kirk originally suggested, should also be accepted.

SUMMARY

On the basis of sparse conodonts, graptolites, and brachiopods, the Heceta Limestone is largely of late Early through Late Silurian age. Although the uppermost 1,500 feet of the formation could be of Devonian age, there is no reliable fossil evidence that it is. The southeast Alaska ranges of *Amphipora* and *Pycinodesma* should be extended into the Silurian.

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