GEOLOGICAL SURVEY RESEARCH 1972

Chapter B

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

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GEOLOGICAL SURVEY RESEARCH 1972

This collection of 39 short papers is the first published chapter of "Geological Survey Research 1972." The papers report on scientific and economic results of current work by members of the Geologic and Water Resources Divisions of the U.S. Geological Survey.

Chapter A, to be published later in the year, will present a summary of significant results of work done in fiscal year 1972, together with lists of investigations in progress, cooperating agencies, and Geological Survey offices.

"Geological Survey Research 1972" is the thirteenth volume of the annual series Geological Survey Research. The twelve volumes already published are listed below, with their series designations.

Geological Survey Research	*Prof. Paper*
1960	400
1961	424
1962	450
1963	475
1964	501
1965	525
1966	550
1967	575
1968	600
1969	650
1970	700
1971	750

MARINE GEOLOGY OF YAKUTAT BAY, ALASKA

By F. F. WRIGHT[1], College, Alaska

Abstract.—Yakutat Bay is a broad, locally shallow coastal embayment exposed by the recession of a piedmont glacier. The morphology and sediments of the bay reflect the complex interaction of glacial, climatic, and marine agents. The bathymetry is dominated by an irregular series of relatively recent moraines left by deglaciation. These moraines are presently being winnowed by tide- and wave-generated currents. Fine sediment, especially mud, is accumulating in the deeper, more sheltered parts of the system. Sand occurs only on modern beaches and in the immediate nearshore zone; gravel occurs on morainal ridges. Values of potential placer accumulations of heavy minerals are low, particularly in the head of the bay.

The University of Alaska and the U.S. Geological Survey have jointly conducted reconnaissance geologic surveys for deposits of heavy minerals in the surficial sediments on parts of the Gulf of Alaska Continental Shelf. This report describes the sediment in the broad, locally shallow embayment of Yakutat Bay near the distal end of the Malaspina Glacier on the Alaskan coast (fig. 1). Other reports discuss similar areas both on the nearby Continental Shelf and in the Nuka Bay area (Reimnitz and others, 1970; Valencia and Wright, 1968; Wright and others, 1968; Wright, 1970).

Acknowledgments.—Many people contributed to various phases of this study. At the University of Alaska, these included Dr. C. M. Hoskin, Department of Geology, and Dr. D. J. Cook, Mineral Industries Research Laboratory, who supervised most of the sediment-size and heavy-minerals analyses, and Cmdr. A. H. Clough (U.S. Coast Guard, retired) and the crew of the RV *Acona*, whose cooperation and efficiency during shipboard operations were outstanding. The study was performed under Office of Marine Geology contract 14-08-001-10885 and was directed by E. H. Lathram and R. E. von Huene, U.S. Geological Survey. The encouragement and critical review of D. M. Hopkins, also of the Geological Survey, are gratefully acknowledged.

METHODS OF INVESTIGATION

Sediment samples, bathymetric records, and seismic profiles were obtained using the University of Alaska's Research Vessel *Acona*. Sediment samples were taken primarily with a Shipek grab to a depth of 10 to 12 cm (4 to 5 inches) in the sea floor; three gravel samples were collected with a small dredge; and four beach samples were taken from the surface at midtide level. Depth records were made with a precision depth recorder (PDR), and acoustic profiles were obtained with a sparker system provided by the Geological Survey. The spark arrays were operated at an approximate energy level of 5 kilojoules; the filters were adjusted to accept acoustic returns in the range 20–200 hertz. Radar was the primary navigational tool, but sextant angles and occasional loran fixes were also used during the survey. Precision of location is estimated to average 0.6 km (0.3 nautical mile).

The sediment samples were processed for size distribution and general mineralogic composition at the University of Alaska. Samples that contained a significant sand and gravel fraction were processed by size. Specific-gravity and magnetic-separation techniques were used for heavy-mineral content, and atomic-absorption procedures were used for specific elements. A sink–float separation with tetrabromoethane (specific gravity 2.96) was used to divide these samples into light and heavy fractions. All samples were analyzed by sieve and pipet techniques to yield percentages of gravel (>2mm), sand (2mm–62μ), silt (62–4μ), and clay (<4μ).

GEOGRAPHIC SETTING

Yakutat Bay is the largest embayment in the Alaskan coast between the fiord areas of Prince William Sound and the Alexander Archipelago of the southeastern Alaska panhandle. The Yakutat Bay area has a maritime-alpine climatic regime typical of the southern Alaska coast. This climate is influenced both by the relatively warm North Pacific Current that flows southeastward along the shelf and by the extensive icefields of the nearby Chugach and St. Elias Mountains (Johnson and Hartman, 1969). The velocity of the North Pacific Current in the Yakutat area is commonly between 77 and 103 cm/second (1.5 and 2 knots); tidal range averages 3.3 m (10.1 feet).

The temperature is generally cool throughout the year, with an annual mean of 40°F (4.4°C). Sea ice does not form in Yakutat Bay, but large quantities of small bergs are produced by the Hubbard and Turner Glaciers, which empty into

[1] University of Alaska, Institute of Marine Science.

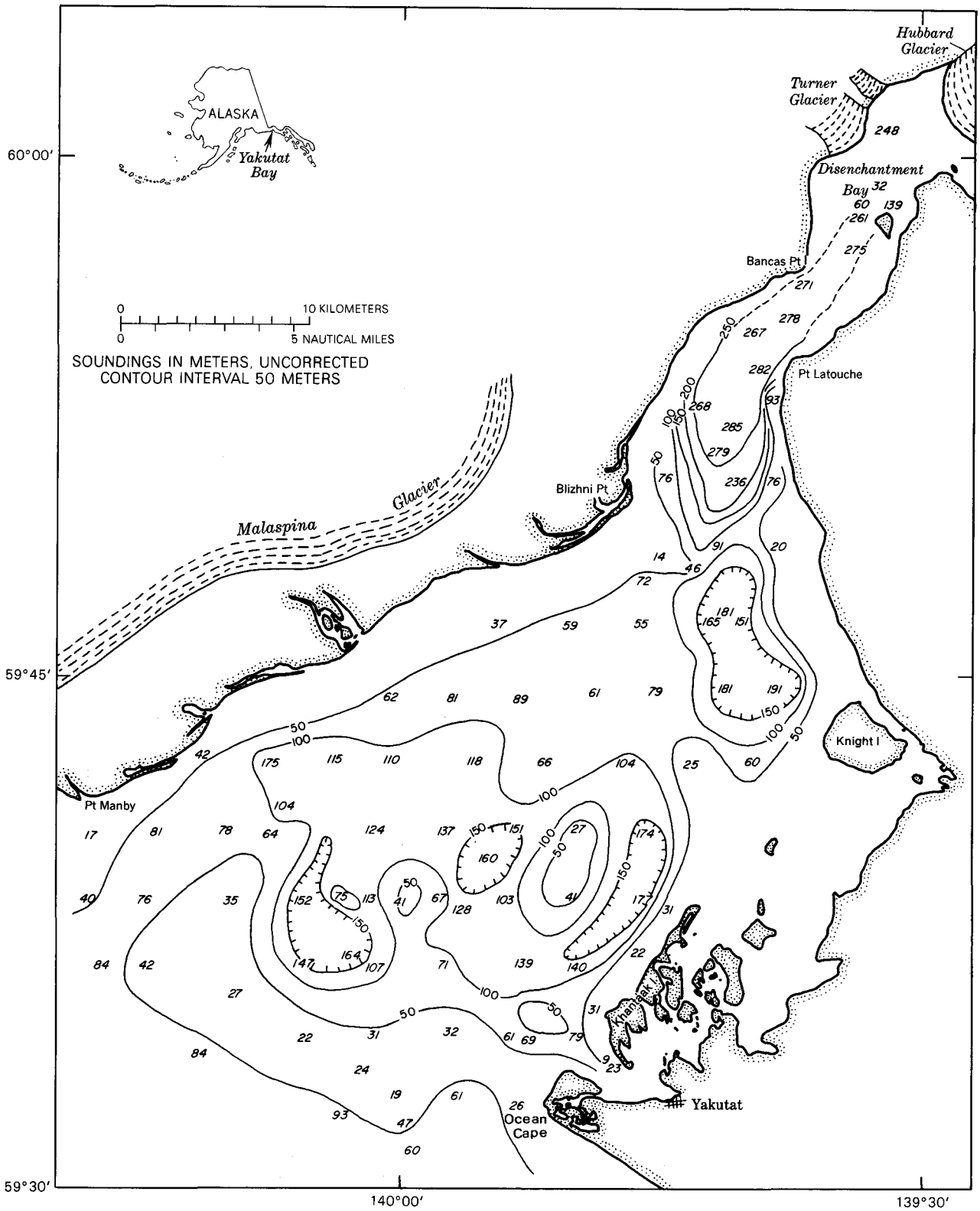

Figure 1.—Bathymetric map of Yakutat Bay, Alaska.

Disenchantment Bay at the head of Yakutat Bay (fig. 1). These small bergs are generally found only in the northern part of the bay (as far south as Blizhni Point), but some have been seen at the mouth of the bay.

Storms occur frequently during the fall, winter, and spring. They are commonly associated with low-pressure cells that are generated in the Aleutian Islands and travel eastward between the continental high and the North Pacific low. These storms dissipate much of their energy in the immediate vicinity of Yakutat Bay and contribute much precipitation to the neighboring icefields. Mean annual precipitation is the highest of any reporting station in the State—over 330 cm (130 inches), including about 546 cm (215 inches) of snow and sleet. The limited fetch available to the intense local storms results in the generation of steep short-period waves, which are undoubtedly an important factor in shallow-water sedimentation in the area. Major long-period waves only occasionally come to the Yakutat area; breakers are then observed along the entire length of the submerged moraine at the mouth of the bay (U.S. Coast and Geodetic Survey, 1964). During the summer there are occasional periods of clear weather along the coast, usually found when a stable low-pressure area in the Gulf of Alaska permits the development of katabatic winds from the St. Elias icefields (U.S. Environmental Science Services Administration, 1967).

Contemporary glaciers in the St. Elias Mountains near Yakutat Bay appear to be predominantly in retreat (Miller, 1964). Miller reported that 82 percent of the glaciers observed in the area were shrinking, 15 percent were in equilibrium, and only 3 percent showed signs of persistent advance. In the immediate area of Yakutat Bay, however, there seems to be a state of quasi-equilibrium. The Turner and Hubbard Glaciers at the head of Yakutat Bay have been advancing steadily into tidewater since 1890 (Miller, 1964). These glaciers have relatively high-elevation névés and have been able to maintain a steady advance into tidewater despite the accelerated wastage associated with a submerged snout (Miller, 1964). In marked contrast, a piedmont glacier, the Malaspina, which is perhaps the largest nonpolar glacier today (Sharp, 1958), appears to be waning. The Malaspina is presently retreating from its most extensive late Quaternary advance, which culminated roughly 1,000 years ago (Plafker and Miller, 1958). This irregular glacial activity appears to have characterized the Gulf of Alaska coastal mountains and shoreline since about late Miocene time (Miller, 1958; Bandy and others, 1969).

GEOLOGIC SETTING

The head of Yakutat Bay penetrates the St. Elias Mountains, a crystalline complex of Mesozoic and older metasediments with minor mafic and quartz monzonitic intrusions (Miller, 1961; Plafker, 1967). Upper Mesozoic and Tertiary sediments, unmetamorphosed but extensively deformed by a series of major thrust faults, underlie the coastal plain and possibly the Continental Shelf (Stoneley, 1967). The bay and its associated seavalley cross the entire coastal plain and Continental Shelf, possibly in a zone of structural transition (Wright and others, 1968).

The coastal plain and some of the coastal mountains are separated by the largest of the faults, the Chugach–St. Elias–Fairweather system, a branch of which forms part of the structural control for the fiords at the head of Yakutat Bay. Movement on this system appears to have included both vertical and right-lateral displacement (Stoneley, 1967).

Another fault, whose presence is inferred from the mapping of a series of uplifted strandlines, was named the Mountain-Front and East Shore fault by Tarr and Martin (1912), who noted that the strandlines were uplifted more than 5 m (17 feet) along the east shore of Disenchantment Bay. The uplift presumably occurred during the Yakutat earthquake of 1899. A later earthquake with major topographic readjustment occurred in 1958 (Miller, 1964).

BATHYMETRY AND SEDIMENTATION

The detailed bathymetric map (fig. 1), which was constructed from data obtained along 160 nautical miles (290 km) of bathymetric profiles during the cruise of the RV *Acona*, shows moderately irregular submarine topography with small-scale hummocks and closed depressions partly smoothed by deposition of contemporary sediment. Relief on the bay floor and on the surrounding coastal plain is largely due to morainal hills left from the most recent advances and retreats of Malaspina Glacier (Plafker, 1967). At the head of the bay is a well-defined closed depression, Disenchantment Basin, with water depths greater than 280 m (919 feet).

South of Disenchantment Bay, three sets of ridges occur within the bay proper. The innermost set extends eastward from Blizhni Point to a position not quite halfway across the bay. Because of the occurrence of gravel at its surface, it is assumed to be a moraine and has been termed the bayhead moraine. This feature has a distinct, apparently unbreached sill with a maximum depth of about 90 m (295 feet). A second but less obvious group of gravel-covered topographic highs extends southwest from Knight Island to the central part of the bay. It includes many depressions and may possibly represent drowned "kettle and kame" topography developed during deglaciation. The largest rise of this group, about 15 km (8.3 nautical miles) north of Ocean Cape, has an elongate streamlined shape suggestive of a drumlin. However, because of the association with other morainal forms, this group of bathymetric highs is also believed to be of morainal origin and has been termed the mid-bay moraine. The third and most clearly defined ridge extends in an arcuate pattern across the mouth of Yakutat Bay from Ocean Cape near Yakutat village toward Point Manby. Most of this ridge, which is designated the baymouth moraine, lies at depths less than 30 m (98 feet). The ridge is breached near its western end by a channel with a maximum depth of 76 m (249 feet). A few miles offshore, within the sedimentary fill of Yakutat Seavalley,

there is at least one probable moraine buried in outwash (Wright and others, 1968).

In order to determine the bedding characteristics within the ridge sets and other sedimentary units, about 290 km (160 nautical miles) of subbottom acoustic profiles were obtained in Yakutat Bay and its tributary fiords. The subbottom profiles were studied not only for thickness and sedimentary features of unconsolidated sediments but also for data concerning the underlying geologic structure. Because the water in Yakutat Bay is shallow and acoustic reflections from the ridge highs are poor, structural features observed in the bay were largely superficial, and analysis was limited to the identification of coherent reflecting horizons.

Subbottom profiles in the broad part of the bay show a distinctive pattern of irregular acoustically opaque rises separated by patches of poorly stratified fill in the deeps (fig. 2). The highs absorb or reflect most of the sonic energy without showing any signs of stratification. The lack of good stratification virtually rules out kame-deposit origin and suggests that the highs are composed of loose heterogeneous material typical of moraines.

In Disenchantment Basin at the head of Yakutat Bay, the acoustical profiles show that the sedimentary fill reaches a thickness of at least 250 m (820 feet) (fig. 2) if a minimum acoustic velocity of 1.5 km/second is assumed in the sediments. The basin serves as a sediment trap, capturing a large amount of the materials being introduced at the head of the bay and from the subsidiary fiords.

Other data concerning the sediments that underlie Yakutat Bay were obtained from 73 surface-sediment stations approximately 3.6 km (2 nautical miles) apart (fig. 3). These sediment samples were taken from the RV *Acona* during the survey and show that gravel-size material is a particularly conspicuous constituent of the topographic highs in Yakutat Bay (fig. 3 and table 1). On the bayhead moraine the gravel occurs in discrete zones and constitutes 89 to 94 percent of the samples. In the area of the mid-bay moraine, only two samples (Nos. 26 and 38) contained significant quantities of gravel (44 and 90 percent). Samples from the baymouth moraine contained the highest gravel concentrations (100 percent in two dredge samples, 74 to 99 percent in three Shipek samples).

Excluding the presumably relict gravel of the morainal ridges, two classes of strictly contemporary sediment are found in the bay: (1) sand, and (2) mud (silt and clay). Sand is a ubiquitous constituent in samples containing gravel (except dredge samples). In eight samples, sand constituted more than 40 percent; in nine samples, sand-size constituents amounted to between 20 and 40 percent. Nearly all these samples came

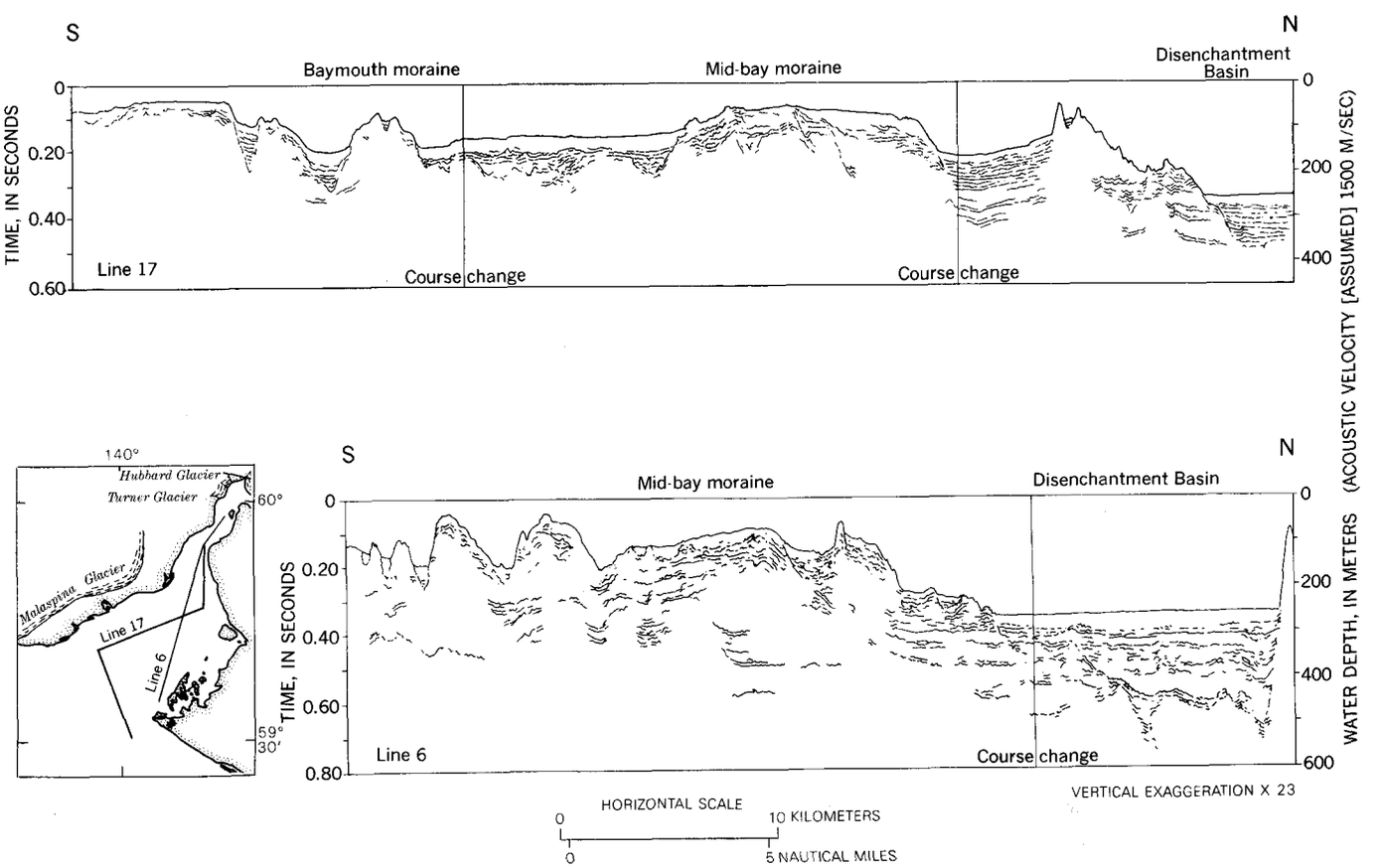

Figure 2.—Subbottom acoustic profiles in Yakutat Bay, Alaska.

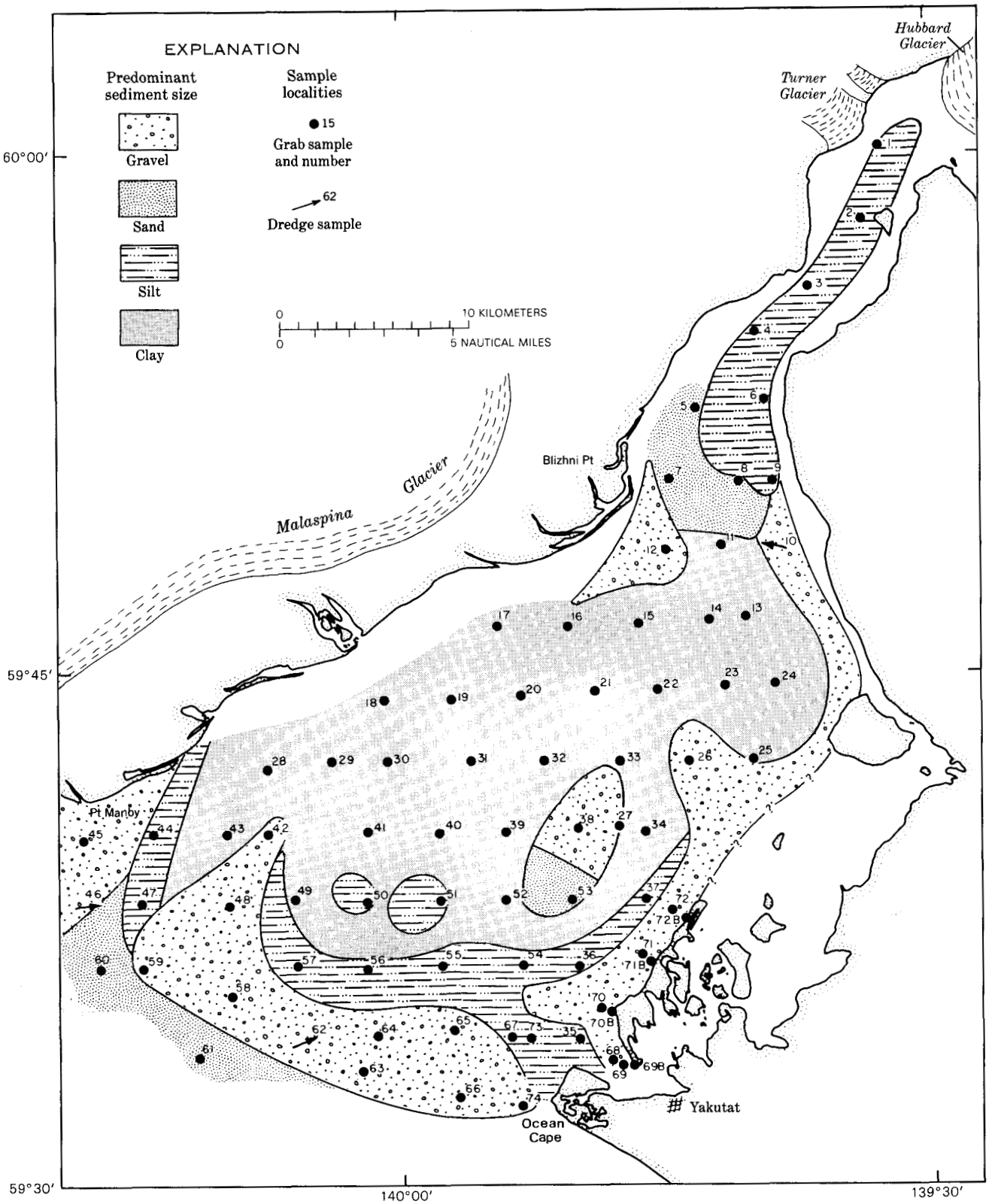

Figure 3.—Sediment distribution and sample localities, Yakutat Bay, Alaska.

Table 1.—*Sediment parameters, in percent, Yakutat Bay, Alaska*

[Analysts: S. M. Valencia, Sally Short, and Richard Nelson]

Station	Gravel	Sand	Silt	Clay	Heavy minerals[1]
1	0	14.37	53.80	31.83	
2	.02	.92	50.70	48.36	
3	.92	3.58	48.20	47.29	17.2
4	2.22	4.85	46.08	46.85	18.1
5	.02	.80	44.20	54.99	
6	.75	1.76	48.49	48.50	18.3
7	.86	47.48	35.26	16.39	
8	.41	42.32	34.24	23.03	
9	1.75	4.71	46.20	47.34	
10	94.18	3.18	1.27	1.37	
11	0	25.15	31.23	43.62	16.0
12	88.98	8.07	1.84	1.10	
13	.95	1.06	31.27	66.73	
14	.72	1.21	33.21	64.86	
15	1.12	2.68	41.08	55.11	
16	.55	2.22	37.95	59.28	
17	.44	1.11	34.23	64.22	
18	1.70	1.85	33.17	63.27	
19	1.12	1.16	29.72	68.00	
20	1.08	.92	13.79	84.21	
21	6.17	4.37	32.75	56.71	16.9
22	0	1.36	39.16	59.48	
23	.56	.83	33.41	65.20	
24	.20	.39	33.60	65.81	
25	11.72	6.50	33.92	47.86	
26	43.92	17.05	18.01	21.02	
27		No recovery			
28	.60	1.21	39.41	58.78	
29	.67	.36	13.74	85.23	
30	.09	.48	30.57	68.86	
31	.10	.47	28.30	71.13	
32	1.22	2.42	40.13	56.22	11.0
33	.03	.42	38.17	61.38	
34	0	2.01	40.33	57.66	
35	0.06	40.36	46.03	13.54	19.5
36	0	22.26	48.16	29.57	
37	0	4.83	52.26	42.90	
38	89.88	9.27	.39	.46	
39	0	1.09	42.54	56.38	
40	.02	1.68	42.74	55.50	
41	0	.70	35.07	64.23	
42	65.33	2.75	17.03	14.89	
43	.71	1.03	32.38	65.88	
44	.06	5.66	53.94	40.34	1.3
45		No recovery			
46	100.00	0	0	0	
47	0	37.98	47.77	14.26	16.6
48	98.79	1.20	0	0	
49	0	.88	32.76	66.35	
50	0	4.60	41.78	53.61	
51	20.80	24.99	31.22	22.98	
52	0	4.50	39.87	55.63	
53	20.57	28.08	27.42	23.92	
54	0	7.15	55.80	37.05	17.1
55	0	24.33	55.49	20.18	19.8
56	0	3.44	48.18	48.37	
57	0	5.63	87.06	7.32	12.0
58	82.25	17.75	0	0	
59		No recovery			
60	.37	49.31	30.78	19.53	13.0

Table 1.—*Sediment parameters, in percent, Yakutat Bay, Alaska*—Continued

[Analysts: S. M. Valencia, Sally Short, and Richard Nelson]

Station	Gravel	Sand	Silt	Clay	Heavy Minerals[1]
61	.04	53.95	38.59	17.24	11.6
62	100.00	0	0	0	
63		No recovery			
64		No recovery			
65	34.95	65.05	0	0	
66	74.10	23.21	2.33	0	12.8
67	0	30.09	50.93	18.99	18.2
68	61.24	27.53	9.19	2.05	
69	.90	77.10	10.24	11.76	15.5
69B	32.43	67.08	.47	0	28.8
70	75.68	19.58	3.76	0.87	
70B	88.82	11.16	0	0	36.1
71	76.29	15.63	1.56	6.66	13.8
71B	80.23	17.98	2.07	0	26.5
72	23.72	10.97	40.20	25.10	
72B	87.70	13.23	0	0	16.5
73	0	48.26	40.78	10.96	20.7
74	66.38	33.22	1.02	0	23.1

[1] Percentage of sand-size fraction.

from locations on or related to topographic highs. The one exception is a sandy silt from the south end of Disenchantment Bay. Across the mouth of Yakutat Bay, just seaward of the morainal gravels, a sand zone is apparently part of the material in active alongshore transport.

The characteristic sediment of the deeper part of the bay is mud made up of roughly equivalent quantities of silt and clay and locally an appreciable admixture of sand with a trace of gravel (table 1). This mud is accumulating as stratified deposits throughout the Yakutat Bay system presently protected from tidal currents or wave action. In the Disenchantment Bay area, close to the tidal glaciers, the mud grades into silt, but the material still closely resembles the mud of the main bay.

Heavy-mineral concentrations observed in the sands of the Yakutat Bay area were moderate to low. They included chlorite, amphibole, and pyroxene, with usually minor quantities of magnetite and ilmenite. Zircon was found in trace amounts. The highest concentrations were in the immediate vicinity of Yakutat village from Ocean Cape to Khantaak Island. The survey did not extend into the shallows eastward of the line between Khantaak and Knight Islands, and sands in this area might also be expected to yield moderate concentrations of heavy minerals. Since the Shipek sampler can collect only relatively small quantities of surficial sediment, this sampling technique is not ideal for heavy-mineral studies. However, the heavy-mineral concentrations summarized in table 1 may be used for preliminary assessments. Additional data are contained in reports by Tarr and Butler (1909) and Thomas and Berryhill (1962).

ECONOMIC GEOLOGY

No significant deposits of economic minerals have been found in the study area, although during the gold rush in the late 1800's there were sporadic efforts to produce gold from the black sands of the local beaches, and various prospectors investigated the neighboring St. Elias Mountains. Beach placers continue to be of potential interest for exploitation, most recently for magnetite and ilmenite as well as for gold and platinum, but no large-scale strikes have been reported in the study area (Tarr and Butler, 1909; Thomas and Berryhill, 1962). The sources of heavy minerals and metals found in the beach sands are presumed to be associated with intrusive bodies of the St. Elias crystalline complex and may well lie beneath the extensive icefields of the coastal mountains (Maddren, 1914).

Oil and gas seeps are found in various parts of the coastal plain centered on Yakutat Bay, and a small oil field of Katalla, 240 km (150 miles) west of Yakutat, was exploited from 1902 to 1933 (Stoneley, 1967). Thirty or more exploratory wells have been drilled on the coastal plain, including several in the immediate vicinity of Yakutat Bay, but no commercial production has been developed (Plafker, 1967).

SUMMARY AND CONCLUSIONS

The marine geology of Yakutat Bay closely reflects the recent glacial and glacial marine history of the area. There is only limited direct contact now with the glaciers of the St. Elias Mountains, but the bay and surrounding coastal plain are dominated by evidence of glacial activity. The entire present bay system has formed since A.D. 1400, the approximate date of the older recession in the region (Plafker and Miller, 1958). Both subbottom records and sediment distribution show the bay to be a pattern of morainal material somewhat modified by contemporary sedimentation and wave and current action.

Sedimentation is very active in the deeper parts of the Yakutat Bay system. Despite the possibility that coarse debris was iceberg rafted, most of the minerals are muds, possibly transported as turbid layers either on the bottom or within the water column (Moore, 1966). Such muds have been termed "periglacial muds" and are thought to be the typical marine sediment associated with active deglaciation (Wright and Sharma, 1969). Sedimentation rates appear to be very high within the entire system, presumably because of the availability of sediments and the activity of the various sedimentary agents (Jordan, 1962).

Heavy minerals are present in the glacial sediments of the Yakutat Bay area. The percentages are highest where contemporary sorting mechanisms, particularly wave attack, have winnowed and concentrated the heavy minerals. The lowest percentages are found toward the head of the bay where sedimentation is so rapid that the heavy minerals are masked by other sediments.

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LEIOSPHAERIDIA (ACRITARCHA) IN THE MESOZOIC OIL SHALES OF NORTHERN ALASKA

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Abstract.—Three collection sites in northern Alaska have yielded *Leiosphaeridia borealis* n. sp. and *L. rugosa* n. sp. from a type of oil shale known as tasmanite. The age of the strata is presumably Jurassic.

A number of reports on the oil shales of northern Alaska have noted that the alga *Tasmanites* makes an oil-rich rock called tasmanite. On microscopic examination, Boneham has found that tasmanite from three different localities also contains the *Leiosphaeridia* genus of Acritarcha, an artificial group of microfossils with uncertain (but undoubtedly both animal and plant) affinities (Evitt, 1963). He describes herein two new species that appear to have contributed to the rich accumulation of organic remains in the tasmanite. The geology on which the Jurassic age is based is summarized by Tailleur.

OIL SHALES

The extensive occurrence of oil shale in northern Alaska has been known for some time (Collier, 1906; Smith and Mertie, 1930). With support from the U.S. Navy through the Office of Petroleum and Oil Shale Reserves and the Naval Arctic Research Laboratory (Office of Naval Research), the U.S. Geological Survey recently began a systematic investigation of the oil yield and areal extent of the oil shale (Tailleur, 1964; Duncan and Swanson, 1965; Tourtelot and Tailleur, 1966; Tourtelot and others, 1967).

Organically rich shales were found in rock units ranging in age from Mississippian to Late Cretaceous (Donnell and others, 1967). The oil yield of the Paleozoic shales is low, however, and attention has been focused on the oil shales of probable Mesozoic age.

Most of the oil shales crop out in terranes of complexly deformed rocks that have not been mapped in enough detail to be defined with confidence. Tasmanite and cannel shale are the richest and most widely distributed types of rock. They are inferred to be Jurassic in age but can be dated with assurance only as post-Mississippian and pre-Cretaceous.

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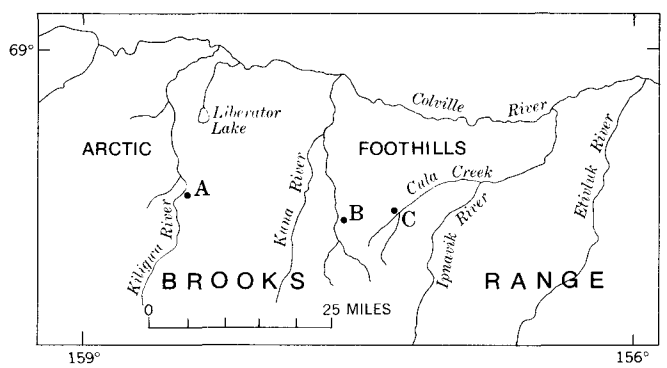
TASMANITE SAMPLES

The three samples of this report were collected by Robert Blair in the west-central part of the southern section of the Arctic Foothills of the Brooks Range (fig. 1). Many of the rocks that form the southern section of the foothills and the western Brooks Range to the south have been strongly dislocated and deformed (Tailleur, 1969a). They appear to have been foreshortened along broad, flat thrusts during the Early Cretaceous to about half their original north-south extent (Snelson and Tailleur, 1968; Tailleur and Snelson, 1969; Tailleur, 1969b).

Tasmanite occurs in two of the several different rock sequences that have been thrust together. The original spatial relation between these two sequences is undetermined. The more widespread sequence (Ipnavik tectonic unit of Snelson and Tailleur, 1968) is characterized by Devonian and Mississip-



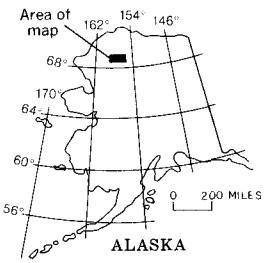


Figure 1.—Map of northern Alaska, showing sample localities. Coordinates: A, 68°44′40″ N., 158°25′40″ W.; B, 68°40′10″ N., 157°33′40″ W.; C, 68°41′40″ N., 157°17′00″ W.

pian carbonates (Baird and Lisburne Groups), numerous diabase sills, and earliest Cretaceous coarse-grained orogenic deposits (Okpikruak Formation). The other sequence is distinguished by an absence of igneous rocks and by earliest Cretaceous fine-grained orogenic deposits. An unnamed unit of varicolored chert is conspicuous in both sequences; clay shale with boudins or thin layers of tasmanite and cannel shale is interlayered with radiolarian chert in the upper part of this unit.

Paleozoic as well as Mesozoic time is represented by the chert unit, but a Jurassic age is inferred for the upper tasmanite-bearing part. In the Ipnavik tectonic unit, the chert unit lies between the Lisburne Group, which is here of Mississippian age, and the earliest Cretaceous Okpikruak Formation; Late Paleozoic fossils have been collected from the base of the chert, and a foraminifer from the clay shale in the upper part has been identified as a Jurassic and Cretaceous form (H. R. Bergquist, written commun., 1952). Further, the upper part appears volcanogenic; volcanic episodes in northern Alaska have been dated as Jurassic from paleontologic data (Imlay, 1955, p. 77, 86; Patton and Tailleur, 1964, p. 444; Jones and Grantz, 1964, p. 1468) and radiometrically (Tailleur and Brosgé, 1970, p. E5). The interlayered cannel shale is very similar to that containing Jurassic fossils (Imlay, 1967, p. 6) in another of the juxtaposed sequences.

Samples A and B appear to be tasmanite from the Ipnavik tectonic unit, in which the varicolored radiolarian chert is associated with diabase sills. Sample C likely represents tasmanite in the other sequence because the outcrop is a few miles north of the mapped limit of the Ipnavik tectonic unit, and no igneous rock was exposed in the chaos of rock types in outcrop (table 1).

SYSTEMATIC PALEONTOLOGY

All specimen numbers refer to the Indiana University, Bloomington, Department of Geology fossil collection. Individual specimens are located on a given slide using an England Finder Slide.

Group ACRITARCHA Evitt, 1963
Subgroup SPHAEROMORPHITAE Downie, Evitt, and Sarjeant, 1963
Genus LEIOSPHAERIDIA Eisenack, 1958
Leiosphaeridia borealis n. sp.

Figure 2, *a*

Description.—Diameter 180μ–450μ; 70 specimens measured, 93 percent are in the size range 200μ–360μ. Wall about 1μ thick. Lunate folds on most of the specimens. None of the specimens has a pylome.

Remarks.—This species resembles *Leiosphaeridia voigti* Eisenack 1958 from the Ordovician of the U.S.S.R. in that they both have lunate folds and thin walls. *L. voigti* has a somewhat smaller size range (190μ–310μ), and many specimens have a

Figure 2.—Two new species of Acritarcha from northern Alaska. Both specimens × 260.
a, *Leiosphaeridia borealis* n. sp. Holotype, IU12132K34/1, locality B.
b, *Leiosphaeridia rugosa* n. sp. Holotype, IU12134H39/4, locality A.

Table 1.—*Relative proportions of* Leiosphaeridia *species at the collecting sites*

Site	Number of specimens		
	L. rugosa	*L. borealis*	*L. rugosa/L. borealis*
A	75	9	8.3
B	89	11	8.1
C	88	12	7.3

pylome. The taxonomic value of the pylome in *Leiosphaeridia* has yet to be decided upon. Apparently in some species it is always present and in others it is rarely, if ever, present; in still other species it may or may not be present on a given individual. Since *L. voigti* usually has a pylome (Eisenack, 1958, p. 392) and since no specimens of *L. borealis* have been found with a pylome (hundreds of individuals were examined in this study), we believe *L. borealis* is distinct from *L. voigti*. *L. plicata* Felix 1965 from the Neogene of southern Louisiana resembles *L. borealis* in the wall folding. However *L. plicata* is smaller (120μ–200μ) and has a thicker wall (3μ–7μ) than *L. borealis*.

Leiosphaeridia rugosa n. sp.

Figure 2, *b*

Description.—Diameter 180μ–400μ; 25 specimens measured, 91 percent in the size range 200μ–380μ. Wall thickness 5μ–7μ. Wall folded in sinuous curves or not folded. No pylome or puncta.

Remarks.—This species bears a remarkable resemblance to *Tasmanites sinuosus* Winslow 1962 from the Upper Devonian and Lower Mississippian of Ohio. They both have the sinuous wall folds, approximately the same diameter (*T. sinuosus* commonly 150μ–325μ), and similar wall thickness (*T. sinuosus* commonly 3μ–10μ). However, as *T. sinuosus* has numerous puncta (a generic character of *Tasmanites*), *Leiosphaeridia rugosa* is easily distinguished from it. The walls of many specimens of *L. rugosa* are somewhat pitted. Because the pitting is irregular on a given specimen and most individuals have rugose walls, we do not believe it is a specific character. The pitting is probably caused by corrosion either from the chemicals used to macerate the rock or by the ground water in the rock. There are some specimens which are gradational between *L. borealis* and *L. rugosa*. They have walls which are 3μ–4μ thick and have lunate folds. There are few such individuals; apparently populations of *Leiosphaeridia* species contain a few gradational forms which defy exact classification. Winslow (1962, p. 82) noted the presence of such forms in populations of *Tasmanites* species as well.

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SOUTHEASTERN ALASKA—A DISPLACED CONTINENTAL FRAGMENT?

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Abstract.—Lower Paleozoic rocks of southeastern Alaska are part of an anomalous continental fragment. Their presence substantiates evidence presented by Monger and Ross in 1971, that a belt of upper Paleozoic rocks along the northern Pacific coast is detached from the main continental mass of North America. Silurian facies trends and other data seem to preclude lateral rifting as the main mode of detachment. Right-lateral transcurrent faulting seems more likely, and California seems to be the only suitable source for the anomalous fragment. Comparison of general lithologies supports the hypothesis that the Klamath Mountains and southeast Alaska are parts of a once-continuous terrane that was dismembered during latest Paleozoic or early Mesozoic time.

Lower Paleozoic sedimentary, volcanic, and plutonic rocks that form the continental crust in southeastern Alaska are anomalous, as similar rocks of comparable age are unknown elsewhere along the northwestern continental margin north of California, and as they appear to be separated from the main continental mass of North America by a belt of younger rocks deposited directly on oceanic crust (fig. 1). These anomalous lower Paleozoic rocks, as well as younger Paleozoic rocks to the south, have been considered by some (Wilson, 1968; Danner, 1970) to be fragments of Asia that were left behind after a collision of Asia and North America. In a recent paper, Monger and Ross (1971) suggest that upper Paleozoic rocks along the coast of British Columbia and southeastern Alaska may be a fragment of the North American Continent that has undergone large-scale movement to attain its present position. Their suggestion is based mainly on the distribution of upper Paleozoic fusulinacean faunas but also takes into account the distribution of lithofacies. Our purpose in this report is to suggest that the anomalous Paleozoic rocks of southeastern Alaska are a displaced fragment of California.

The belt of lower and upper Paleozoic rocks along the coast of southeastern Alaska and British Columbia (Monger and Ross' western belt), is separated from the main continental mass of North America by an extensive parallel belt of upper Paleozoic rocks thought to be deposited directly on oceanic crust (Monger and Ross' central belt). The northwestern part of the western belt consists of a block of old Paleozoic continental crust that constitutes the Alexander Archipelago and contiguous areas of southeastern Alaska. Its continental nature is indicated by a long record of sedimentation and intermittent volcanism (Brew and others, 1966) beginning at least as early as Ordovician and extending through the Paleozoic into the Mesozoic, and by intrusion of granitic rocks of Ordovician and Silurian ages (Lanphere and others, 1964, 1965). The history of the southeastern Alaskan block is complex, and the record of sedimentation is broken by many unconformities that indicate intermittent uplift and erosion (Ovenshine and others, 1970).

The eastern and southern parts of the western belt consist of upper Paleozoic sedimentary and volcanic rocks discussed by Monger and Ross; these extend south along the coast of British Columbia and terminate against the trans-Idaho discontinuity of Yates (1968). Precambrian and older Paleozoic rocks apparently do not underlie these parts of the western belt. The relation of the older Paleozoic rocks in southeastern Alaska to the upper Paleozoic rocks occurring nearby to the east and southeast is not clearly defined; the contact may occur on Annette and Gravina Islands in southeastern Alaska where a complex zone of major thrusting has been inferred by H. C. Berg (oral commun., 1971).

The oceanic nature of the upper Paleozoic rocks in the central belt to the east is indicated by the presence of abundant ultramafic rock associated with gabbro, pillow basalt, chert, and other sedimentary rocks including fusulinid-bearing limestones (Monger and Ross, 1971).

DISTRIBUTION OF PERMIAN FUSULINACEAN FAUNAS

The existence of distinctly different but coeval Permian fusulinid faunas has long been recognized (for an excellent review, see Ross, 1967). In British Columbia, Monger and Ross (1971) showed that two well-defined fusulinacean assemblages occur in separate belts. One assemblage, dominated by genera of the family Schwagerinidae, forms an eastern belt (Monger and Ross, 1971, fig. 2); the other, dominated by genera of the family Verbeekinidae, forms a central belt. In a belt lying west of the central belt, along the coast of British Columbia and in

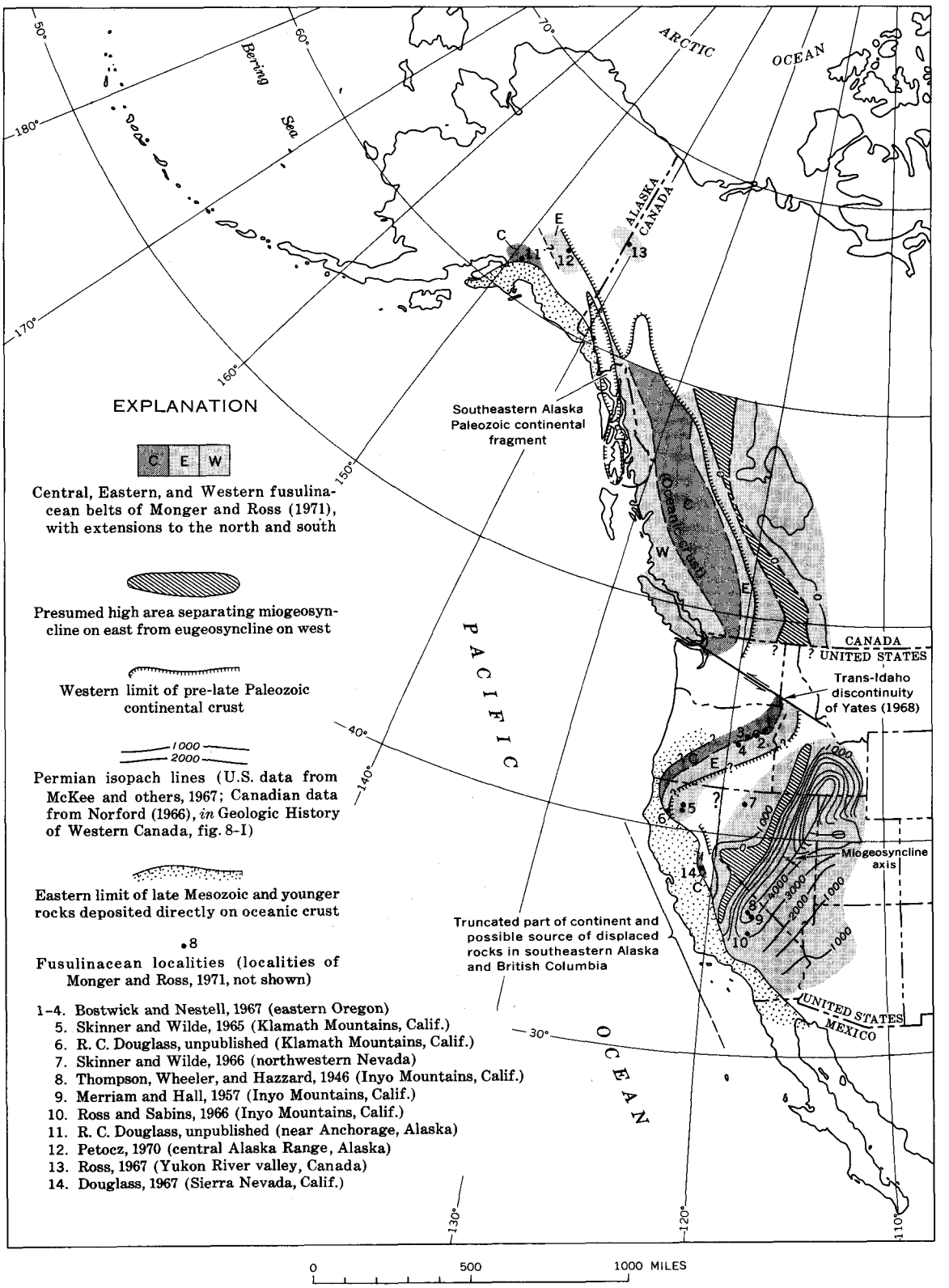

Figure 1.—Map showing distribution of Permian fusulinacean faunas and position of displaced continental fragment in southeastern Alaska.

southeastern Alaska, Permian rocks contain Schwagerinid faunas similar to those of the eastern belt. The Schwagerinid faunas of both the eastern and western belts show close ties to other North American faunas of the same age; the Verbeekinid faunas of the central belt show close ties to faunas from Japan and elsewhere in Asia and are referred to as Tethyan (Ross, 1967; Gobbett, 1967; Bostwick and Nestell, 1967; Douglass, 1967). Hamilton (1969, p. 2412) has suggested that Permian terranes bearing Tethyan fusulinid faunas in western North America may have formed in an island arc in the north-central Pacific and were later swept against the continent. We accept the view of their extracontinental origin, but not necessarily the island arc environment.

Three models are proposed by Monger and Ross (1971) to account for this pattern of faunal belts. The first model is ecological, in which the differing fusulinid faunas result from differences in local environment. The second and third models are tectonic. The second envisages simple splitting and separation parallel to the continental margin, with generation of new oceanic crust within the widening rift zone and concomitant subduction on both sides of the rift. The eastern and western belts would thus be dismembered portions of the same terrane. The central belt, confined to the new oceanic crust, would present different ecological conditions and hence would be characterized by a different fauna. The third model is one in which a continentward Schwagerinid zone and an oceanward Verbeekinid zone are cut by a major right-lateral transcurrent fault, such that some of the eastern zone comes to lie west of part of the central zone.

It is instructive to examine the distribution of Paleozoic rocks and trends of facies along the continental margin of North America to determine whether the source of the dislocated terrane can be located. On figure 1 we have extended the eastern and central belts of Monger and Ross south through Oregon and north into Alaska, based on published information and on unpublished identifications by R. C. Douglass. We have used the same faunal criteria for these extensions as were used by Monger and Ross for British Columbia.

Our basic premise is that the late Paleozoic continental margin of much of western North America is defined approximately by the boundary between the eastern and central fusulinacean belts. Hence, where this boundary is continuous and can be observed, significant post-Paleozoic truncation of the continent has not occurred. In areas near the coast where the central belt is missing, however, truncation may have occurred. Any such truncated area should be evaluated as a possible source terrane for the displaced Palezoic rocks of southeastern Alaska.

The western fusulinacean belt is restricted to British Columbia and southeastern Alaska as shown by Monger and Ross. To the north, in southern Alaska, the presence of the eastern belt has been established by the work of Ross (1967) in northwest Canada and of Petocz (1970) in the central Alaska Range (locs. 12 and 13, fig. 1). The presence of the central belt is indicated by Tethyan fusulinids collected near Anchorage (loc. 11) by Sandra Clark and identified by R. C. Douglass. Permian rocks extend farther to the southwest, but, as they have not yielded fusulinids, the distribution of the belts cannot be discerned. South of Alaska the central (oceanic) belt can be traced through central Oregon and may occur in California. South of British Columbia the eastern fusulinacean belt broadens to cover much of the Western United States and continues southward beyond the last trace of the central belt.

The boundary between the eastern and central belts occurs in eastern and central Oregon (loc. 1–4, fig. 1) where both Verbeekinid and Schwagerinid faunas have been described (Bostwick and Nestell, 1967, p. 95). To the southwest, Schwagerinid faunas are well developed in the McCloud Limestone (loc. 5) (Skinner and Wilde, 1965) and elsewhere in the eastern half of the Klamath Mountains (loc. 6).

Rocks similar to those of the central belt are present in the western Klamath Mountains of California, but a Tethyan affinity has not been established on a paleontologic basis. According to N. J. Silberling (oral commun., 1971) a marginal sea with oceanic crust may have existed in late Paleozoic time east of the Klamath Mountains. If this is so, then in northern California and central Oregon the margin defined by the boundary between the central and eastern fusulinacean zones occurs on a microcontinental fragment lying west of the main continental mass.

In the foothills of the Sierra Nevada, Calif., three occurrences are known of Tethyan fusulinids in limestone in the western outcrop belt of the Calaveras Formation (loc. 14, fig. 1) (Douglass, 1967; Clark, 1964, p. 13–14). At least one of these occurrences is a limestone block incorporated in younger rocks (Clark, 1964, p. 13–14). Possibly the other occurrences are displaced tectonically and thus may not accurately represent the extent of the central belt or the position of the Paleozoic continental margin.

FACIES TRENDS AND TRUNCATION OF WESTERN NORTH AMERICA

Distribution of the fusulinacean belts and some other elements of the Paleozoic of western North America is shown on figures 1, 2, and 3. In British Columbia, Permian isopachs and Silurian and Ordovician lithologic belts trend parallel to the coastline, but to the south, after apparent left-lateral offset by the trans-Idaho discontinuity, they trend southwestward at a large angle to the Pacific coastline. In California the trends of older Paleozoic rocks of the main continental mass of western North America clearly are truncated (Hamilton and Myers, 1966, p. 513; Hamilton, 1969, p. 2412), as are the fusulinacean belts. The Mesozoic rocks west of the truncated Paleozoic rocks trend northwestward and lack an older continental basement (Irwin, 1964, p. C4; Hamilton, 1969; Bailey and others, 1970).

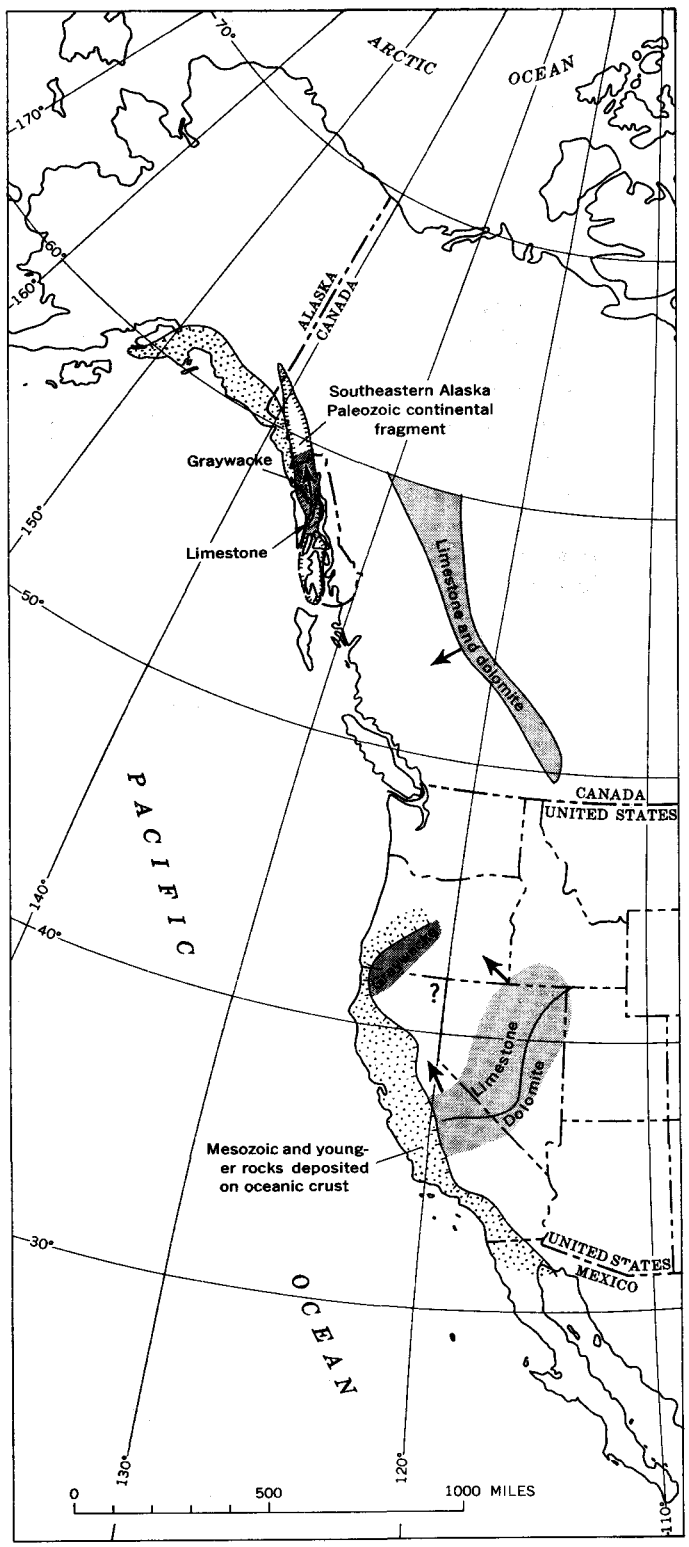

Figure 2.—Distribution of Silurian facies belts, showing truncation of trends in California. Arrows show main direction of change in facies. Data for southwestern United States from Merriam (unpub.); for Alaska from Ovenshine (unpub. palinspastic reconstruction); and for Canada from Norford (1966).

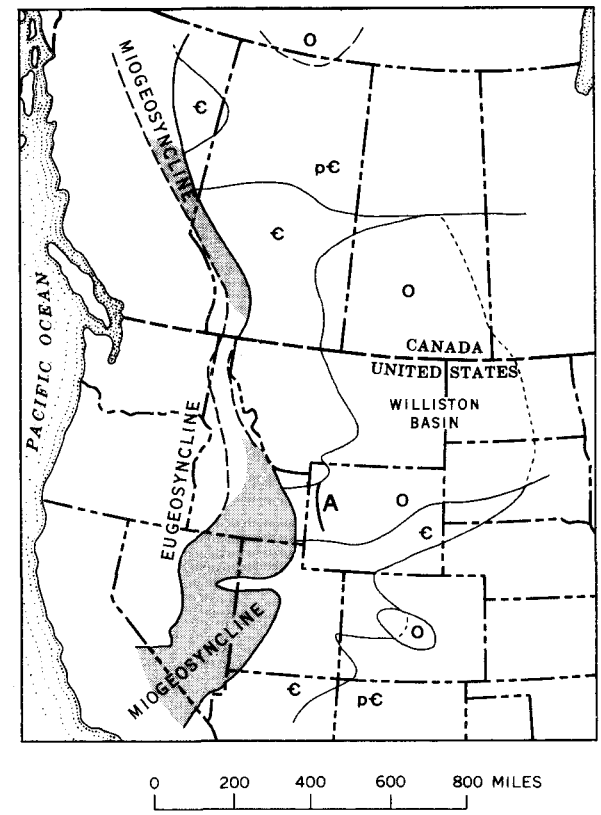

Figure 3.—Western North America, showing extent of Ordovician quartzite (shaded) in the miogeosyncline; and Precambrian (p€), Cambrian (€), and Ordovician (O) terranes east of the geosyncline. A, western limit of Ordovician quartz sand in the Williston basin (from Ketner, 1968, p. 170, fig. 1).

SOURCE OF CONTINENTAL FRAGMENT

The fusulinacean data from the western belt suggest that the displaced rocks along the coast of British Columbia and Alaska have close ties to continental North America, rather than having originated in Asia. Movement of the displaced rocks could have been by rifting with generation of the central oceanic belt in the growing rift zone, by lateral faulting along transform faults, or by some other means such as large-scale thrust faulting. Monger and Ross (1971, p. 276) pointed out that their rifting model is not supported by faunal data. It is also not supported by an analysis of Silurian facies trends.

The generalized distribution of Silurian sedimentary rocks is shown in figure 2, with the direction of dominant change in facies from shallow-water carbonates to deeper water graywacke and flyschlike deposits indicated by arrows. In California and Nevada, the direction of facies change is northwesterly (C. W. Merriam, unpub. data; Berry and Boucot, 1971), and in southeastern Alaska it is similar although slightly more northerly. These directions contrast markedly with the direction of facies change in British Columbia. There the lithologic

belts trend northwesterly (Norford, 1966), and the direction of facies change is southwesterly at nearly right angles to that of southeastern Alaska. This difference strongly suggests that the southeastern Alaska terrane was not detached from the main continental mass nearby in British Columbia unless it was subsequently rotated through a large angle. Rather, the similarity in direction of change of facies in California and southeastern Alaska suggests that the Silurian rocks of these two areas could have been deposited within the same general terrane. This possibility is supported by a close similarity of the Silurian rocks in the two areas.

Middle and Upper Silurian rocks of southeastern Alaska comprise a southern belt of limestone and conglomerate and a northern belt of calcareous graywacke. Clasts of andesite, chert, and diorite are conspicuous in the conglomerate zones, which are locally as much as 2,000 feet thick. Similar conglomerate also occurs locally in the time-equivalent graywacke sequence to the north. In the Klamath Mountains, Middle and Upper Silurian rocks (lower part of the Gazelle Formation) consist of graywacke, mudstone, conglomerate, limestone, and volcanic rocks (Wells and others, 1959). As in southeastern Alaska, some of the conglomerates contain clasts of andesite and diorite (Rohr and Boucot, 1971). Also, Silurian faunas from southeastern Alaska have close affinities with those of the Klamath Mountains (Churkin and Langenheim, 1960).

This similarity of Silurian rocks and faunas in southeastern Alaska and in California permits the speculation that the southeastern Alaskan continental fragment originated in California and was rafted northward following truncation of the continent. This speculation is comparable to Monger and Ross' (1971, p. 275, fig. 5) model involving major transcurrent faulting, although they did not suggest a possible source for the dislocated upper Paleozoic terrane.

A detailed comparison of the geology of the possible source area and the presumed detached fragment will not be attempted in this short report, but a summary of the stratigraphic units in southeastern Alaska, the Klamath Mountains, and the Inyo Mountains of California is given in table 1 (p. B216).

This table shows that whereas the Paleozoic rocks of southeastern Alaska are not like those of the western Great Basin, represented by the miogeosynclinal rocks of the Inyo Mountains, they do resemble the eugeosynclinal rocks of the eastern Klamath Mountains, although stratigraphic details are highly discordant. Rapid and drastic facies changes along strike coupled with structural complexity characterize the Paleozoic rocks in both places, as is shown by the detailed stratigraphic studies of Eberlein and Churkin (1970) in southeastern Alaska, and by the difficulty in correlating the Paleozoic stratigraphy of the eastern Klamath Mountains with that of the nearby Taylorsville area of the northern Sierra Nevada (compare Irwin, 1966, p. 23, with McMath, 1966, p. 176). Hence, it may be unreasonable to expect a closer fit in lithologic details than the table demonstrates. In any case, it is obvious that if the southeastern Alaskan Paleozoic rocks were derived from California, they could only have come from the northern part of the State, as the rocks in the southern part are wholly dissimilar. The fate of the truncated miogeosynclinal Paleozoic rocks and the Precambrian basement rocks of southern California is unknown.

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Table 1.—*Comparison of stratigraphic sequence in southeastern Alaska with that of the Klamath Mountains and Inyo Mountains, California*

Age	Southeastern Alaska (data from Eberlein and Churkin, 1970, and Lathram and others, 1965)	Eastern Klamath Mountains, California (data from Irwin, 1966)	Inyo Mountains, California (data from McKee and Nelson, 1967; Ross, 1966)	
Permian	Pybus Formation — Dolomite and chert Cannery Formation—argillite, graywacke, chert, minor volcanic rocks	Dekkas Andesite—fragmental lava, pyroclastics, and minor sedimentary rocks Nosoni Formation—mudstone and tuff McCloud Limestone—massive limestone and chert	Owens Valley Formation Keeler Canyon Formation	Limestone and shale Limestone and shale
Pennsylvanian	Klawak and Ladrones Formations—sandstone and limestone	Baird Formation, upper part		
Mississippian	Peratrovich Formation — Thick-bedded limestone, limestone, and chert Chert, minor limestone	Baird Formation, lower part—pyroclastic rocks, mudstone, keratophyre Bragdon Formation—shale, sandstone, conglomerate, chert, and pyroclastic rocks	Rest Spring Shale Perdido Formation	Shale and siltstone Shale, siltstone, sandstone, and conglomerate
Devonian	Port Refugio Formation—graywacke, shale, volcanic rocks Wadleigh Limestone — St. Joseph Island Volcanics (Devonian?) Coronados Volcanics	Kennett Formation—mudstone and tuff Balaklala Rhyolite—quartz keratophyre and tuff Copley Greenstone—keratophyre and spilite	Sunday Canyon Formation/ Vaughn Gulch Limestone (Silurian and Devonian?)	Argillaceous limestone and mudstone/limestone
Silurian	Karheen Formation—sandstone and shale Heceta Limestone—massive limestone, with minor sandstone and conglomerate	Gazelle Formation—graywacke, mudstone, conglomerate. Includes Payton Ranch Limestone Member of Churkin and Langenheim (1960)		
Ordovician	Descon Formation—graywacke, mudstone, siltstone, conglomerate, minor limestone, and volcanic rock (Ultramafic basement)	Duzel Formation (Ordovician?)—phyllitic graywacke, chert, and limestone (Ultramafic basement)	Ely Springs Dolomite Johnson Spring Formation Barrel Spring Formation Badger Flat Limestone Al Rose Formation	Dolomite and chert Quartzite, dolomite, limestone Shale, limestone, quartzite Limestone, siltstone, quartzite Shale, mudstone, limestone
Cambrian			Tamarack Canyon Dolomite Lead Gulch Formation Bonanza King Dolomite Monola Formation Mule Spring Limestone Saline Valley Formation Harkless Formation Poleta Formation Campito Formation Deep Spring Formation Reed Dolomite Wyman Formation	Dolomite Cherty limestone, shale, dolomite Dolomite and limestone Siltstone and limestone Blue-gray limestone Siltstone and quartzite Shale and quartzite, minor limestone Shale, limestone, and quartzite Siltstone, shale, and sandstone Quartzitic sandstone and limestone Buff to gray dolomite Argillite and quartzite
Precambrian				

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