GEOLOGICAL SURVEY RESEARCH 1969

Chapter D

GEOLOGICAL SURVEY PROFESSIONAL PAPER 650-D

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

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GEOLOGIC STUDIES

GEOLOGICAL SURVEY RESEARCH 1969

This collection of 45 short papers is the third published chapter of "Geological Survey Research 1969." The papers report on scientific and economic results of current work by members of the 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 during fiscal year 1969, together with lists of investigations in progress, reports published, cooperating agencies, and Geological Survey offices.

"Geological Survey Research 1969" is the tenth volume of the annual series Geological Survey Research. The nine volumes already published are listed below, with their series designations.

Geological Survey Research 1960—Prof. Paper 400
Geological Survey Research 1961—Prof. Paper 424
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RECONNAISSANCE GEOLOGY OF THE MOUNT EDGECUMBE VOLCANIC FIELD, KRUZOF ISLAND, SOUTHEASTERN ALASKA

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

Abstract.—The postglacial Mount Edgecumbe volcanic field contains at least 14 rock units ranging in composition from olivine-augite basalt to augite-bearing quartz latite. Mesozoic graywacke and slate and Tertiary granitic intrusions underlie the gently dipping basalt which forms the base of the pile. Andesite and basaltic andesite overlie the basalt near Mount Edgecumbe and, in turn, they are probably overlain by the dacitic rocks which make up the composite cone of Mount Edgecumbe proper and by dacite flows and cinder cones on its southwest flank. Mount Edgecumbe and a nearby remnant of a similar cone are cut by latite domes. The remnant is now the site of a caldera 1.6 kilometers in diameter and 240 meters deep. Widespread dacite(?) lapilli and ash probably resulted from explosive eruptions during the formation of the composite cones. Nine chemical analyses define a smooth compositional trend that correlates with the relative age of the map units. The magma series is calc-alkaline and has a close relationship to the high-alumina basalt series.

Mount Edgecumbe is an inactive volcano 26 kilometers west of Sitka, Alaska (figs. 1, 2, and 3). The mountain is part of a Pleistocene and Holocene volcanic field that covers about 260 square kilometers on the southern end of Kruzof Island. The field consists of gently dipping flows, composite cones, and air-fall ash and lapilli. Augite basalt seems to be the most common rock type; olivine basalt, basaltic andesite, hypersthene dacite, and quartz latite are also present.

With the exception of Quaternary(?) vents on Lisianski Inlet, Chichagof Island (Rossman, 1959, p. 186), there are no known Holocene volcanic areas within 240 km of Mount Edgecumbe (Brew, Loney, and Muffler, 1966). The scattered vents of interior British Columbia are 240 to 320 km away (Little, 1962); those of southern southeastern Alaska are 320 km distant; and the volcanic seamounts of the Gulf of Alaska, a few of which could be Holocene, are also at least 320 km away. The volcanic field is far distant from those in the Aleutian Islands (Coats, 1950) and the Wrangell Mountains (fig. 1).

The Mount Edgecumbe volcanic field is closer to the continental margin (as defined by the 100-fathom contour) than are the volcanoes of the interior conterminous United States, Canada, and Alaska, and is even closer than most Aleutian volcanoes (fig. 1). Thus the Mount Edgecumbe field may provide an informational link between the continental volcanoes and the volcanic seamounts of the Gulf of Alaska (Engel and Engel, 1963).

Unsubstantiated (and probably inaccurate) accounts of volcanic activity at Mount Edgecumbe within historic time have been summarized by Becker (1898, p. 13). Two radiocarbon dates provide evidence about the absolute age of the major eruptions of Mount Edgecumbe. One date, from peat underlying an ash layer near Juneau, suggests that large-scale ash and lapilli eruptions from Mount Edgecumbe occurred about 9000 Before Present (Heusser, 1960, p. 97, 184). This date is in good agreement with one of 8750±300 B. P. for rooted wood at the base of a peat layer that overlies the Mount Edgecumbe ash at Sitka (R. W. Lemke, U.S. Geological Survey, oral commun., 1966).

The Mount Edgecumbe volcanic field has been visited by few geologists. William Libbey, Jr., a geographer, visited the field in 1884 (Libbey, 1886, p. 283–286), and H. F. Reid climbed Mount Edgecumbe in 1892 (Cushing, 1897). F. E. Wright, of the U.S. Geological Survey, climbed the volcano in 1904 and studied some of the rocks but never published his results. Adolph Knopf, also of the Geological Survey, visited the east side of the field briefly in 1910 (Knopf, 1912, p. 14) and described a specimen of the most common flow rock. Berg and Hinckley (1963, p. O14–O15) mapped the northeast corner of the field and described the major features briefly.

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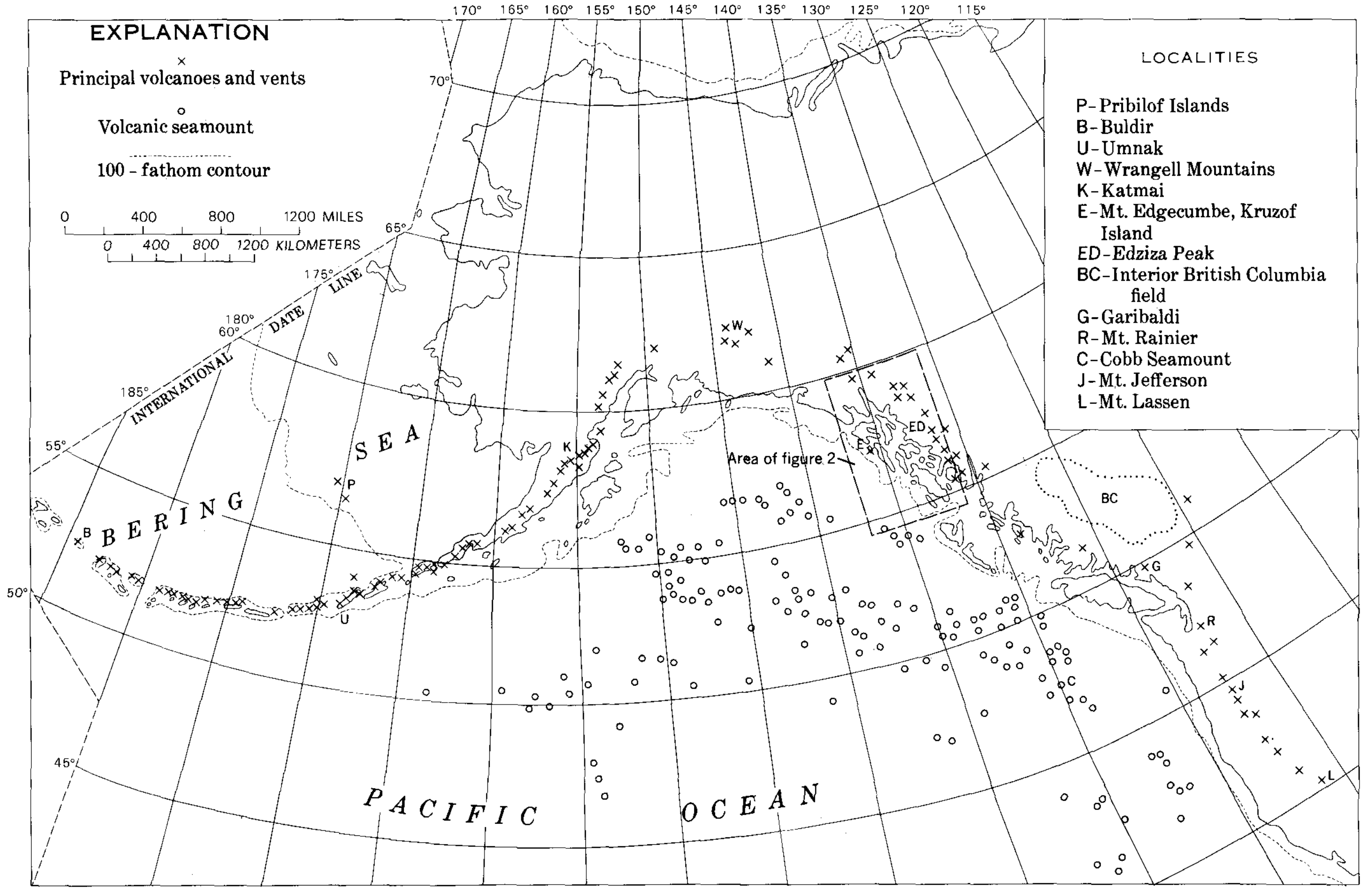


FIGURE 1.—Map of northeastern Pacific region, showing location of some Plio-Pleistocene, Pleistocene, and Holocene volcanoes (x), volcanic seamounts (o), 100-fathom contour (short dashes), and outline of figure 2.

The present study is based on reconnaissance mapping of the shoreline in August 1961 by R. A. Loney and D. A. Brew, with some additional data provided by H. C. Berg and J. S. Pomeroy, and on reconnaissance mapping of the shoreline and island interior in June and August 1962 by D. A. Brew and L. J. P. Muffler. A preliminary photogeologic map of the island was compiled by J. S. Pomeroy and combined with field data by L. J. P. Muffler in 1962. Preliminary petrographic examinations by H. C. Berg in 1961 were used in the preparation of a preliminary map covering the area (Loney and others, 1963). The petrographic studies were completed by D. A. Brew. Some preliminary results of our studies were reported by Brew, Muffler, and Loney (1966).

In the petrographic study of the Edgecumbe Volcanics, flat-stage methods were used in examining both thin sections and grain mounts. Precise mafic mineral determinations have not been made, although refractive indices of olivine and clinopyroxene were measured in some specimens. Determinative curves from Tröger (1959) were used. Plagioclase compositions were obtained from extinction-angle data and checked in high-dispersion oils, using the method of Emmons and Gates (1948) and the curves of Tsuboi (1923). Modal values were estimated visually from thin sections. The volcanic rocks were classified by means of Peterson's (1961) criteria. In addition, the rock names are modified by prefixing the names of the most important mafic minerals in the specimen. Thus an olivine-bearing augite basalt is a basalt containing more than about 10 percent augite and less than 10 percent olivine in the phenocrystic and groundmass phases taken together. Nine chemical analyses were obtained to verify the compositional classification of critical specimens and to provide a basis for better comparison of this volcanic field with others. Semiquantitative spectrographic analyses for 50 elements were also obtained from these nine specimens (Heropoulos and Mays, 1969).

This brief report cannot do justice to the complicated eruptive and petrogenetic history of the Mount Edgecumbe volcanic field, but it summarizes our present interpretations and hopefully will encourage a detailed study of the area.

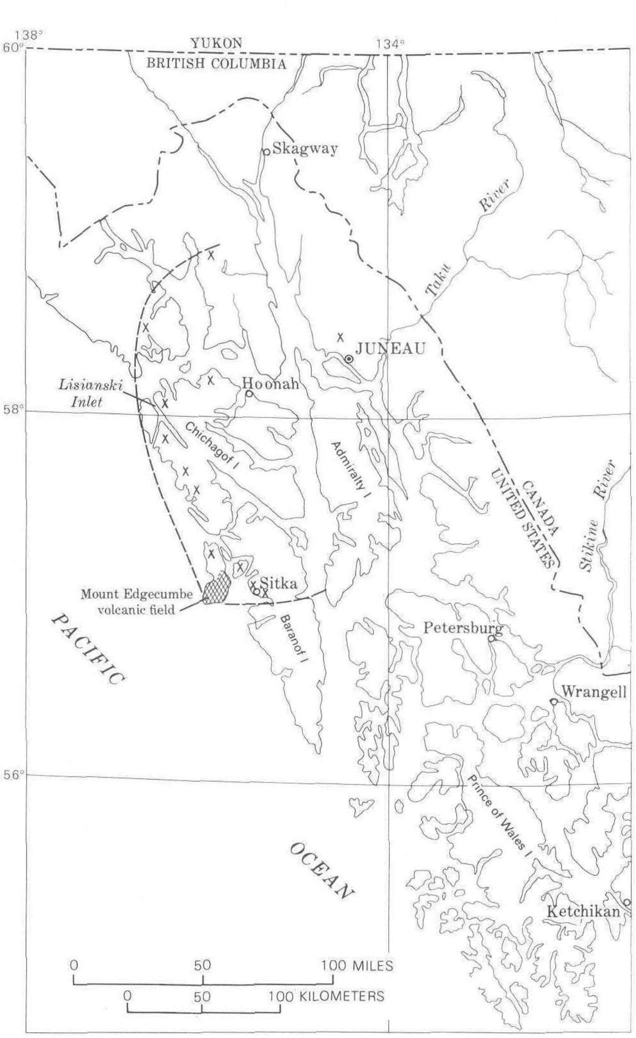


FIGURE 2.—Map of southeastern Alaska, showing location of Mount Edgecumbe volcanic field. Localities where Mount Edgecumbe ash is known to have been deposited are indicated by X. Dashed line is inferred limit of Mount Edgecumbe ash.

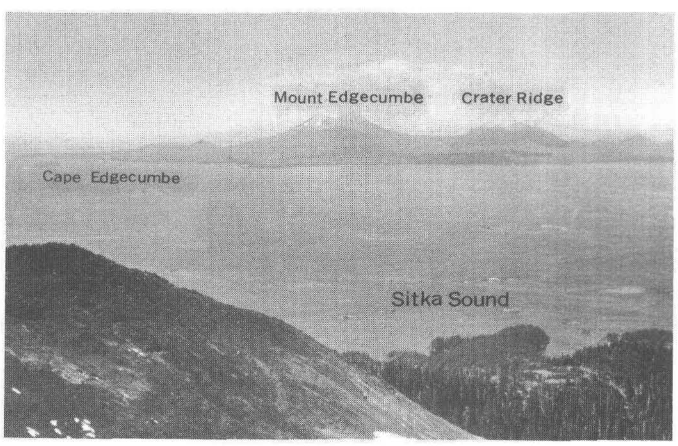


FIGURE 3.—Mount Edgecumbe volcanic field viewed from 29 km southeast across Sitka Sound. Mount Edgecumbe is 976 m high. The part of Kruzof Island shown in the photograph is about 16 km from left to right.

We thank James G. Smith and Donald A. Swanson for critically reviewing the manuscript.

STRATIGRAPHY AND PETROGRAPHY

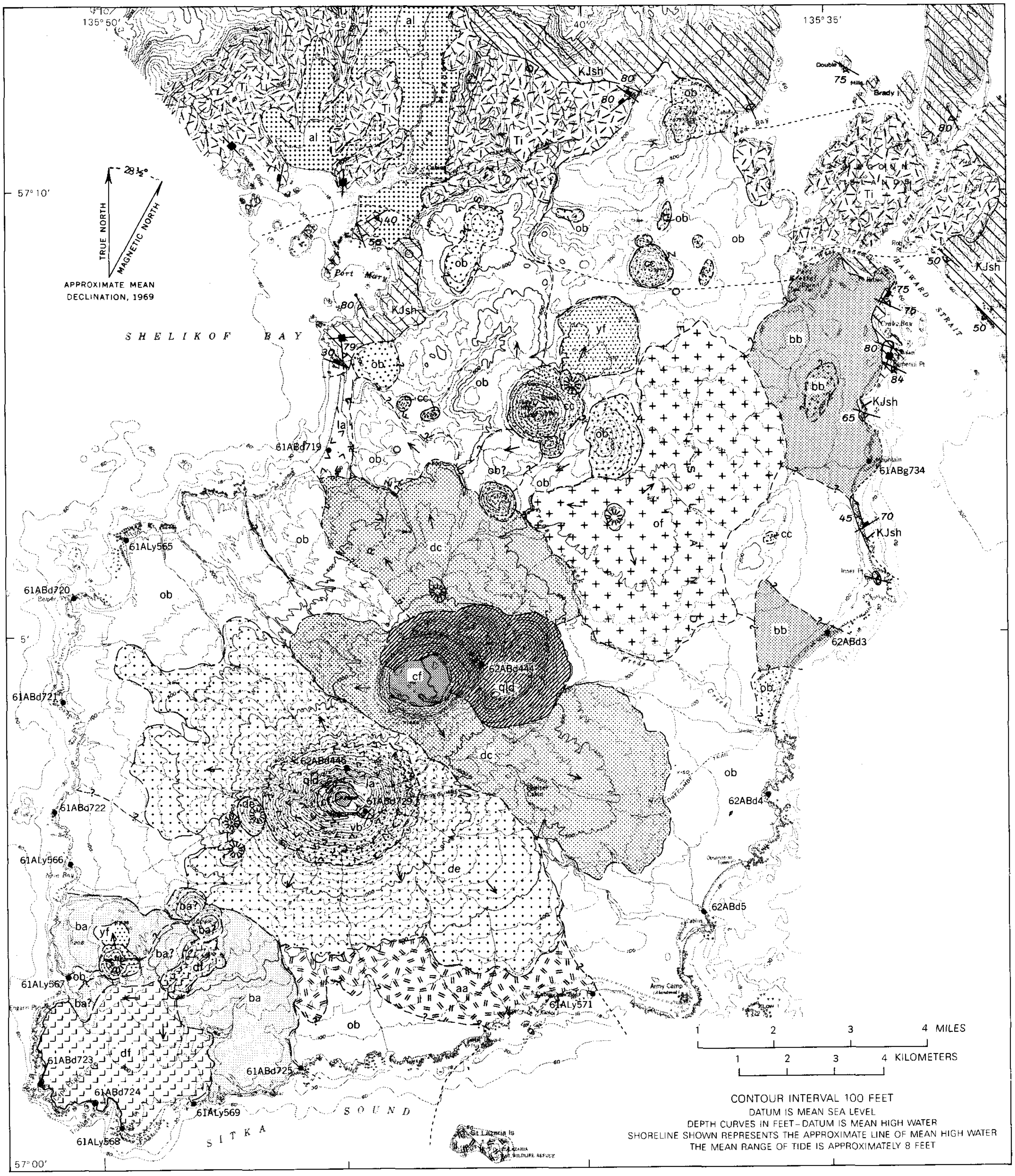
Basement rocks

The volcanic rocks of the Mount Edgecumbe volcanic field were extruded onto a glacially planed surface of Mesozoic graywacke and slate that had been intruded by Tertiary granitic rocks (fig. 4). The graywacke and slate are part of the Sitka Graywacke (Berg and Hinckley, 1963, p. O12–O14; Loney and others, 1963, p. 5; Loney and others, 1964). Unmetamorphosed Sitka Graywacke consists of highly folded thin– to medium-bedded dark-gray graywacke interlayered with dark-gray slate. Although exposed only on the Vitskari Rocks and Vitskari Island (east of Low Island, fig. 4), unmetamorphosed Sitka Graywacke probably underlies the southern third of the volcanic field. The Sitka Graywacke in the northern part of the volcanic field has been thermally metamorphosed to biotite-plagioclase-quartz hornfels and schist, garnet-biotite-plagioclase-quartz hornfels, cordierite-biotite-plagioclase-quartz hornfels, and chlorite-plagioclase-quartz hornfels and schist. These thermally metamorphosed rocks are well exposed along the east shore of Kruzof Island, where they are locally highly sheared, mostly along north and northwest trends, and range in strike from west-northwest to north. Steeply dipping dikes of porphyritic basalt are exposed where the covering volcanics have been stripped off along the shore by wave erosion. The dikes are 1 to 15 meters wide and trend either about north-south or east-west.

The intrusions which thermally metamorphosed the Sitka Graywacke in Tertiary time (Loney and others, 1967) consist of light-gray medium-grained biotite granodiorite, biotite adamellite, and biotite granite (Loney and others, 1963, table 1) and probably underlie a third of the volcanic pile. The presence of granodiorite clasts among the ejecta at the summit of Mount Edgecumbe and as boulders in streams draining from wholly volcanic areas south of Shelikof Bay indicates that the magma conduits in those areas are at least partly within the intrusive rock.

Edgecumbe Volcanics

The volcanic rocks of southern Kruzof Island, named the Edgecumbe Volcanics by Berg and Hinckley (1963, p. O14–O15), are unglaciated and rest uncomformably on a low-relief glaciated surface that truncates all rocks older than the volcanic rocks. The volcanic rocks are overlain by alluvial deposits north and east of Shelikof Bay (fig. 4).



Base from U.S. Geological Survey
Sitka A-5 and A-6, 1951

Geology by D. A. Brew, R. A. Loney, L. J. P. Muffler, H. C. Berg, J. S. Pomeroy, and D. W. Hinckley, 1960-62

FIGURE 4.—Reconnaissance geologic map of the Mount Edgecumbe volcanic field, Kruzof Island, southeastern Alaska.

EXPLANATION

QUATERNARY

Holocene

al — Alluvium

Pleistocene and Holocene — *Late Wisconsin* — Edgecumbe Volcanics

yf — Younger unsampled flows and associated cinder cones

cc — Young unsampled cinder cones

cf — Caldera fill and crater subsidence deposits

vb — Vent breccia

la — Lapilli and ash
Probably mantles all older units

of — Older unsampled flows and associated cinder cones

qld — Quartz latite domes

df — Dacite flows and associated cinder cones

de — Dacite
Dacite of Mount Edgecumbe cone and associated cinder cones

dc — Possible dacite
Possible dacite of Crater Ridge and associated cinder cone

ba — Basaltic andesite
Basaltic andesite north and east of Cape Edgecumbe

aa — Andesite
Porphyritic hypersthene andesite of St. Lazaria Islands

bb — Basalt and breccia
Dense olivine basalt and associated breccia of Mountain Point

ob — Oldest basalt flows
Vesicular porphyritic olivine-bearing basalt

UNCONFORMITY

TERTIARY

Eocene

Ti — Intrusive rocks
Biotite granodiorite, adamellite, and granite

JURASSIC AND CRETACEOUS

Upper Jurassic and Lower Cretaceous

KJsh — Hornfels and schist
Biotite-garnet and biotite-cordierite hornfels and schist derived from Sitka Graywacke

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——— — — — ?- - -
Contact
Long-dashed where approximately located; short-dashed where indefinite or inferred; queried where hypothetical; dotted where concealed. Used both within and between map units

55 Inclined — 80 Overturned — Vertical
Strike and dip of beds
Dot indicates top of beds known from sedimentary structures

65 Inclined — Vertical
Strike and dip of foliation in layered rocks

71 Inclined — Vertical
Strike and dip of joint or joint set

→
Direction of lava flow as inferred from pressure ridges, tunnels, and (or) general configuration

Cinder cone and (or) eruptive vent

•61ABd720
Location and number of thin-sectioned specimen of Edgecumbe Volcanics

FIGURE 4.—(CON.)

The Edgecumbe Volcanics contains flows, minor intercalated breccias, cinder cones, and steep-sided domes. The volcanic field is dominated by one large composite volcanic cone, Mount Edgecumbe, and also contains a collapsed composite cone, Crater Ridge, and several smaller cinder cones, all of which stand above a broad base made up of many thin flows. Both composite cones and all but the youngest lava flows appear to be mantled by unconsolidated lapilli and ash.

The major vents are alined in a narrow 24-km-long belt that trends N. 30° E. Some of the youngest activity appears to have been concentrated near the southwestern tip of the island, but the overall eruptive sequence indicates no systematic change of active vent locations.

We have subdivided the Edgecumbe Volcanics into 14 units (table 1; figs. 4 and 5); their stratigraphy and petrography are treated separately below.

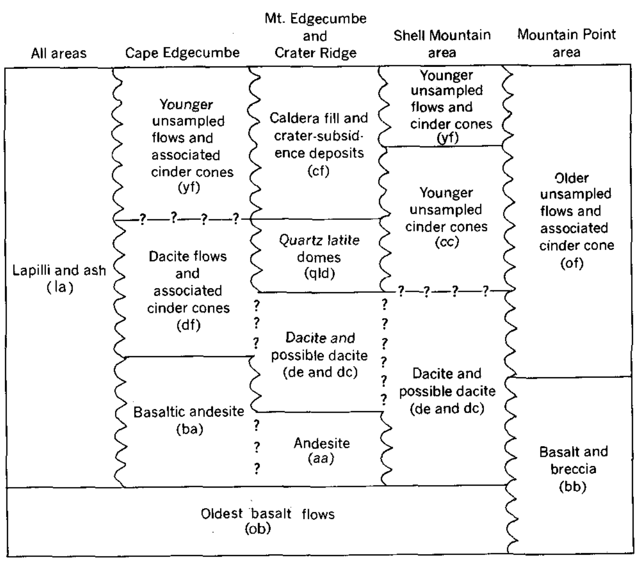

FIGURE 5.—Correlation chart showing reconnaissance subdivision of Edgecumbe Volcanics. Vertical position in chart shows probable place in eruptive sequence. Solid lines indicate stratigraphic relation known. Queried solid lines indicate stratigraphic position inferred. Wavy vertical lines separate geographic groups of units whose mutual relations are not known. Queries along vertical lines indicate possible correlation between units in adjacent columns. Lowercase letters in parentheses are map symbols used on figure 4. Vent breccia (vb of fig. 4) not shown on chart because of uncertainty of its age relation to crater fill and crater subsidence deposits.

Oldest basalt flows.—Most of the broad platform that underlies the spectacular composite cones of southern Kruzof Island consists of medium-gray vesicular porphyroaphanitic olivine-bearing augite basalt flows (fig. 4). These flows are characterized by 10–30 percent vesicles, 5–40 percent plagioclase phenocrysts, and scattered olivine phenocrysts 0.5–1 millimeter in diameter. Individual flows range from 0.5 m to a few meters in thickness and commonly have chilled bottoms and highly vesicular oxidized pahoehoe tops. Other features include (1) well-developed polygonal columns 0.3–1.2 m across and (2) abundant pressure domes and ridges up to a few hundred meters in maximum dimension and as much as 2 m high. The flanks of these domes and ridges have dips as steep as 50°.

Other rock types have been locally included in the "oldest basalt flows" unit (fig. 4). Interlayered breccia and medium- to dark-gray slightly vesicular basalt occur about 1 mile northeast of Beaver Point on the west coast of the island. Both the basalt flow and the fragments in the breccia are slightly porphyritic olivine-bearing augite basalt. The breccia fragments range from 2 centimeters to 1 meter in maximum dimension, and some bomblike fragments were noted. A sequence of pahoehoe flows with minor breccia layers has also been included in the map unit north of Neva Bay. These flows are composed of light- to medium-gray porphyritic to microporphyritic vesicular olivine-augite basalt. The flows contrast with those typical of the "oldest basalt flows" unit because of their slightly greater olivine content, poorer columnar jointing, thinness (average 30–50 cm), and relatively small (3-m diameter) domes. The breccia interlayers are 2–6 m thick and consist of angular to subangular fragments, 1 cm to 1 m in diameter, of flow-rock lithic type in a soft fine-grained tuff matrix.

Another group of flows included in the "oldest basalt flows" unit occurs along the shore due south of Mount Edgecumbe. These flows are light- to medium-gray, coarsely vesicular, microporphyritic augite-bearing olivine basalt. They are further characterized by polygonal columns 0.5–1 m in diameter, small domes, and rare pahoehoe tops; single flows are probably a few meters thick.

Petrographic characteristics of thin-sectioned specimens from the "oldest basalt flows" are given in table 1. These flows are typified texturally by vesicularity, abundant phenocrysts, and intergranular groundmass textures. The low amount of olivine phenocrysts and the consistent olivine and plagioclase compositions (table 1) are important. A consistent range of clinopyroxene compositions was not obtained from the optical data, and the mineral is therefore reported simply as augite, although most is probably diopsidic augite and some is subcalcic augite.

Fine grain size made it difficult to determine compositions and proportions of groundmass olivine and clinopyroxene and to determine the presence or absence of reaction relations around olivine phenocrysts.

Several significant petrographic features common to all specimens are not shown in table 1 and are therefore noted here. Plagioclase phenocrysts commonly are progressively zoned over a range of 30 percent An from core to rim with conspicuous oscillatory zoning near the rims. Their composition in table 1 is representative of the "outer core" and is practically an average for the phenocryst. In some of the specimens, the phenocryst outlines are irregular owing to reaction with the groundmass material after crystallization or with the magma.

Another striking feature of some of these basalts is the presence of glomeroporphyritic clots of plagioclase and mafic crystals as large as 1 cm in diameter.

Minerals derived from olivine after crystallization are described in table 1 simply as an orange-brown or red-brown secondary mineral. Probably this late product is "bowlingite" or "iddingsite." Chlorophaeite present in a few specimens is included with the glass in table 1.

Three samples (61ABd720, 61ABd725b, and 61ALy-566) of the "oldest flows" were analyzed chemically (columns 2, 3, and 4, table 2).

Basalt and breccia.—A lithologically distinct unit consisting of volcanic breccia overlain by dense massive lava flows is exposed in two areas along the east shore of Kruzof Island. Between Port Krestof and Mountain Point the unit rests uncomformably on hornfels derived from the Sitka Graywacke. South of Inner Point the unit has been interpreted from photogeologic evidence to rest on the "oldest basalt flows," but the evidence is poor. The stretch of shore separating the northern and southern exposures is made up of hornfels overlain by "oldest basalt flows."

The relations of the "basalt and breccia" unit to the other rock units in the volcanic field are not clear from the available reconnaissance data. The unit is considered younger than the "oldest basalt flows" (fig. 5) and probably older than the "older unsampled flows," but could antedate or be coeval with the "oldest basalt flows" unit.

The lower part of the "basalt and breccia" unit is volcanic breccia consisting of bomblike or pillowlike fragments of vitrophyre and dense nonvesicular slightly porphyritic olivine basalt as much as 75 cm in maximum dimension in a poorly sorted matrix of irregularly shaped breccia fragments and tuff. The breccia is variable in thickness and locally contains fragments that appear to be weathered fine-grained graywacke; this latter feature suggests that subaerially weathered debris was incorporated in the breccia during movement. The "basalt and breccia" unit may have been erupted, at least in part, from a dissected cone about 2.4 km northwest of Mountain Point.

Flows of olivine basalt compositionally similar to the large fragments in the breccia overlie the breccia. The flows are subhorizontally layered, massive, dense, fine grained, and generally nonvesicular. In places erosional remnants of the flows rise above the breccia and superficially resemble dikes.

The augite-bearing olivine and olivine-augite basalts are characterized by the absence or near absence of vesicles and phenocrysts (table 1). The available petrographic data suggest that this unit may contain a variety of rock types and, perhaps, compositions. One sample (61ABg734d) from the "basalt and breccia" unit was analyzed chemically (column 1, table 2).

Andesite.—A distinctive unit of subhorizontal andesite flows is well exposed along the shore near Lava and Goloi Islands and on St. Lazaria Islands (fig. 4). These flows probably came from near Mount Edgecumbe. The andesitic composition suggests affinity with rocks of Mount Edgecumbe rather than with the "oldest basalt flows," which the andesites are interpreted to overlie and which they resemble in outcrop.

The unit consists of nonvesicular, highly porphyritic, dark-gray olivine-bearing hypersthene andesite or basaltic andesite flows a few meters thick. The andesites have excellently developed joint columns about 30 cm in diameter that are oriented perpendicular to flow surfaces. The andesite flows are also characterized by abundant domes as much as 15 m across and a few meters high, and the columns appear to radiate from many centers beneath the domes. Locally the flanks of the domes dip as steeply as 40°.

Petrographic features of the andesite (table 1) include the following: abundant broken plagioclase phenocrysts and microphenocrysts that are partly replaced by an epidotelike mineral, synneusis-twinned plagioclase phenocrysts, glomeroporphyritic clots of plagioclase and locally corroded pigeonitic augite, hypersthene apparently intergrown with clinopyroxene and plagioclase, and rare quartz xenocrysts.

One sample (61Ly571) of this andesite unit was analyzed chemically (column 6, table 2). Comparison of the analysis with Nockolds' (1954) averages suggests that the rock is best called an andesite.

Basaltic andesite.—Low on the southwest flank of Mount Edgecumbe are rocks mapped separately (fig. 4) as basaltic andesite. The flows probably originated from now slightly dissected cinder cones at elevations between 700 and 1,200 feet and spread over the southwestern part of Kruzof Island. They rest on the "oldest basalt flows" unit on the south side of the island and between Engano Point and Neva Bay on the west side

TABLE 1.—*Petrographic characteristics of thin-section specimens from*

[Specimen locations shown on figure 4. Asterisk (*) indicates chemically analyzed specimen. Abbreviations—General: Comp., composition; Tr., trace; V, very. Mineral: m, medium;

Specimen No.	Rock name	Texture							Composition (percent)					
		General (percent)		Specific		Average phenocryst size (mm)			Plagioclase				Olivine	
									Phenocrysts		Groundmass		Phenocrysts	
		Vesicles	Phenocrysts	Whole rock	Groundmass	Plagioclase	Olivine	Pyroxene	Total	An content	Total	An content	Total	Fa content
OLDEST BASALT FLOWS (ob)														
Typical flows														
61ABd720*	Vesicular porphyritic olivine-bearing augite basalt.	≈25	42	Porphyro-aphanitic.	Intergranular	1×3	0.6	--------	30	50–60	46	50–55	8	5–10
61ABd721b	do	≈15	25	do	Intergranular to micro-ophitic.	1×5	1×1.7	--------	22	57	52	57	3	12–15
62ABd5	do	≈30–40	40	do	Intergranular	1×3	0.6	--------	35	61	30	48	5	15–25
62ABd4	Vesicular porphyritic augite-olivine basalt.	≈35	28	do	do	0.8×3.5	0.5	--------	25	62	35	54	3	15–20
Less typical breccia fragment														
61ALy565a	Vesicular porphyritic olivine-bearing augite basalt.	≈10	10	Porphyro-aphanitic.	Intergranular to felty.	1×3	2	--------	6	60	47	60	3	20–23
Other flows														
61ABd722a	Vesicular porphyritic olivine-augite basalt.	≈20	22	Porphyro-aphanitic.	Intergranular and intersertal.	0.5×1	0.8	--------	12	70	15	54	10	15
61ALy566*	Vesicular microporphyritic augite-olivine basalt.	≈10	--------	Microporphyro-aphanitic.	Felty intergranular to intersertal.	--------	--------	--------	5	48	55	51	3	15
61ABd725b*	Vesicular microporphyritic olivine basalt.	≈15	--------	do	Intergranular to intersertal.	--------	--------	--------	2	60	56	48	3	10–15
BASALT AND BRECCIA (bb)														
61ABg734a*	Olivine-pigeonitic augite basalt.	--------	--------	Aphanitic	Microophitic to intersertal.	--------	--------	--------	--------	--------	53	59	--------	--------
62ABd3	Slightly vesicular porphyritic olivine basalt.	≈5	7	Vitrophyric.	Hyalopilitic.	--------	0.7–3.0	--------	--------	--------	47	56	7	10–15
ANDESITE (aa)														
61ALy571*	Porphyritic hypersthene basaltic(?) andesite.[1]	--------	40	Vitrophyric.	Hyalopilitic	0.75	0.2–0.6	0.2–0.6	30	65	20	46	2	10–20
BASALTIC ANDESITE (ba)														
61ALy567a*	Porphyritic olivine-bearing pigeonite basaltic andesite.[1]	--------	20	Porphyro-aphanitic.	Felty intersertal.	0.5×1	1	0.5	15	58	38	50	4	15–25
61ALy567b	Porphyritic hypersthene-bearing olivine basalt or basaltic andesite.	<2	25	do	Felty intergranular.	2	0.7	0.6	18	60	49	54	5	10
61ALy569a	Slightly vesicular porphyritic olivine-bearing pigeonite basalt or basaltic andesite.	≈5	15	do	Felty intersertal.	0.4×0.8	0.9	?	9	52	50	52	3	0–5
61ALy569c	Slightly vesicular porphyritic olivine-bearing pigeonite basaltic andesite.	<5	20	do	Felty intersertal to pilotaxitic.	0.6×1	0.6	0.6	16	53	20	48?	4	15
61ABd725c	Slightly vesicular porphyritic olivine-bearing pigeonite?-augite basaltic andesite.	10	20	do	Felty intersertal.	0.8	0.3	1.5	15	55	50	47–55	1	15

See footnotes at end of table.

the Edgecumbe Volcanics, Kruzof Island, southeastern Alaska

Pg, subcalcic augite; Di, diopside; Hy, hypersthene; Au, augite; Mg, magnetite; Il, ilmenite; Hm, hematite. Color: or, orange; br, brown; gn, green; gy, gray; dk, dark; lt, light]

Composition (percent)																
Olivine		Clinopyroxene				Orthopyroxene				Opaque minerals		Glass		Secondary minerals		Remarks
Groundmass		Phenocrysts		Groundmass		Phenocrysts		Groundmass								
Total	Fa content	Total	Comp.	Total	Comp.	Total	Comp.	Total	Comp.	Total	Type	Total	Description	Total	Description	
OLDEST BASALT FLOWS (ob)																
Typical flows																
1	12	4	Pg?	9	Pg?					1	Mg?	1		Tr.	Or br	
2	12–15	15	Ti rich							3	Mg, Il?	3	Murky	Tr.	do	Probable reaction around olivine.
3	15–25	5	Di?	15	Di?					5	Mg?			2	do	
15	5–15			16						5	do	Tr.?		1	do	No reaction around olivine.
Less typical breccia fragment																
1	23	1	Di?	25	Au					10	Mg?	5	Devitrified.			Possible reaction around olivine.
Other flows																
Tr.	15			27	Di?					20	Mg?	10		Tr.	Red br	No reaction around olivine.
12	15-20			12	do					7	do	6	Dk br, murky.	Tr.	Gn, or-br.	Olivine has magnetite+clinopyroxene rims; microphenocryst composition is given.
24	10–15			5	Pg?					3	do	6	do			Possible reaction around olivine; microphenocryst composition is given.
BASALT AND BRECCIA (bb)																
17	10–15			20	Pg			1	Hy	5	Mg	4	Br, gn, devitrified.	1	Gn chlorite?	
10	10–15			4	Au							32	V dk br			No reaction around olivine.
ANDESITE (aa)																
		2?	Pg?			6	Hy	5	Hy?	15	Mg?	18	Dk	2	Murky	10 percent plagioclase microphenocrysts included with phenocrysts; 5 percent hypersthene microphenocrysts included with groundmass; one quartz phenocryst noted.
BASALTIC ANDESITE (ba)																
		1	Pg?	25	Pg					2	Mg?	15	Br, gy, murky.			Olivine has clinopyroxene rims; excellent flow alinement around phenocrysts.
4?		1	Au	15	Au	1	Hy	?		4	do	3	M br			Olivine has clinopyroxene rims; proportion of orthopyroxene may be > given; one exotic sphene grain noted.
1?		3	Pg?	20	Pg					8	do	15	Lt m br.	1	Chlorophaeite.	Possibly two generations of plagioclase phenocrysts; olivine has clinopyroxene+magnetite rims; 5 percent "late alkalies" in groundmass.
1?		4	Pg?	43	Pg?					8	do	8	M br			Plagioclase and olivine phenocrysts reacting with groundmass.
		4	Pg	10	Au					10	do	10	Dk br			Plagioclase, olivine, and pigeonite phenocrysts reacting with groundmass.

TABLE 1.—*Petrographic characteristics of thin-section specimens from*

[Specimen locations shown on figure 4. Asterisk (*) indicates chemically analyzed specimen. Abbreviations—General: Comp., composition; Tr., trace; V, very. Mineral: m, medium;

Specimen No.	Rock name	Texture: General (percent): Vesicles	Texture: General (percent): Phenocrysts	Texture: Specific: Whole rock	Texture: Specific: Groundmass	Average phenocryst size (mm): Plagioclase	Average phenocryst size (mm): Olivine	Average phenocryst size (mm): Pyroxene	Composition (percent): Plagioclase: Phenocrysts: Total	Composition (percent): Plagioclase: Phenocrysts: An content	Composition (percent): Plagioclase: Groundmass: Total	Composition (percent): Plagioclase: Groundmass: An content	Composition (percent): Olivine: Phenocrysts: Total	Composition (percent): Olivine: Phenocrysts: Fa content
DACITE (de)														
62ABd446*	Slightly vesicular porphyritic augite andesite(?) [2]	≈8	25	Porphyro-aphanitic.	Hyalopilitic	0.2	-------	0.4	17	55	43	43	-------	-------
DACITE FLOWS (df)														
61ABd723a	Lineated porphyritic pyroxene andesite or trachyandesite.	-------	5	Porphyro-aphanitic.	Pilotaxitic	1	-------	-------	[3] 3	64	40	43	-------	-------
61ABd723d*	Porphyritic augite-hypersthene andesite or trachyandesite. [2]	-------	7	do	do	-------	-------	-------	[5] 4	78	40	35	-------	-------
61ABd724c	Vesicular porphyritic hypersthene-augite andesite?	20	4	do	Hyalopilitic	0.5×1	-------	-------	3	46	[8] 55	47	-------	-------
61ALy568	Porphyritic hypersthene-augite andesite or trachyandesite.	-------	8	do	Pilotaxitic	0.3×0.8	-------	0.3×0.5	[9] 5	53	23	33	-------	-------
QUARTZ LATITE DOMES (qld)														
62ABd444*	Banded porphyritic augite-bearing andesite or trachyandesite. [10]	≈2	5	Vitrophyric	Felty hyalopilitic.	0.5×1	-------	0.3×1	4	46?	40	37	-------	-------
VENT BRECCIA (vb)														
61ALy729b	Vesicular porphyritic augite-bearing andesite? or trachyandesite?	15	25	Porphyro-aphanitic.	Intersertal to inter-granular.	-------	-------	-------	[11] 10	50	35	35–39	-------	-------
LAPILLI AND ASH (la)														
61ABd719-1	Pyroxene- and plagioclase-bearing pumice.	40	5	Holohyaline	-------	0.3×1	-------	-------	5	-------	-------	-------	-------	-------
61ABd719-2	Hypersthene- and plagioclase-bearing pumice.	50	4	do	-------	-------	-------	-------	2	33	-------	-------	-------	-------

[1] Andesite on basis of chemical analysis.
[2] Dacite on basis of chemical analysis.
[3] Twenty percent microphenocrysts of An_{42} and An_{55} (two generations).
[4] Two percent augite microphenocrysts also.
[5] Ten percent microphenocrysts of An_{53} and An_{38} also.
[6] One percent augite microphenocrysts also.

the Edgecumbe Volcanics, Kruzof Island, southeastern Alaska—Continued

Pg, subcalcic augite; Di, diopside; Hy, hypersthene; Au, augite; Mg, magnetite; Il, ilmenite; Hm, hematite. Color: or, orange; br, brown; gn, green; gy, gray; dk, dark; lt, light]

Composition (percent)																Remarks
Olivine		Clinopyroxene				Orthopyroxene				Opaque minerals		Glass		Secondary minerals		
Groundmass		Phenocrysts		Groundmass		Phenocrysts		Groundmass								
Total	Fa content	Total	Comp.	Total	Comp.	Total	Comp.	Total	Comp.	Total	Type	Total	Description	Total	Description	
DACITE (de)																
		7	Au	10	Au	1?				7	Mg?	15	Devitrified?			Proportion of orthopyroxene may be greater than given.
DACITE FLOWS (df)																
		[4] 2	Au	12	Au	2	Hy			15	Mg?	6	Gy br			
		[6] 1	Au	28	Au	[7] 2	Hy			8	do	5	Murky			
				10	?	1	Hy			6	do	25	Br, murky.			
		1	Au	15	Au	2	Hy			12	do	12	Lt-m-br			Hypersthene has narrow reaction rim with groundmass; most mafic phenocrysts in glomeroporphyritic clots.
QUARTZ LATITE DOMES (qld)																
		Tr.	Au							10	Mg?, Il?	45	Devitrified.	4	Hm	1 percent of opaques are phenocrysts.
VENT BRECCIA (vb)																
		5	Pg?	15	Au	10	Hy			10	Mg?	5	Gy br			Plagioclase phenocrysts broken and reacted; hypersthene phenocrysts have reaction rim with groundmass.
LAPILLI AND ASH (la)																
		7								2	Mg?	93	Colorless			
						2	Hy					94	Lt br			2 percent lithic fragments (also dark-brown vesicular glass with plagioclase phenocrysts).

[7] One percent hypersthene microphenocrysts also.
[8] Actually microphenocrysts.
[9] Thirty percent microphenocrysts of An_{60}? also.
[10] Quartz latite on basis of chemical analysis.
[11] Ten percent microphenocrysts of An_{50} also.

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and are overlain by the "dacite flow and associated cinder cone" unit and some of the "younger unsampled flows." The relation to the "andesite" unit, which the basaltic andesite also contacts, is unclear.

The rocks of this unit are porphyroaphanitic olivine-bearing pigeonite basaltic andesites (table 1). They are nonvesicular to slightly (10 percent) vesicular and commonly contain 15–20 percent phenocrysts (mostly plagioclase) that are 1–2 mm long. Some vitrophyres and breccias are interbedded with the usual flow rocks. In general the unit is characterized by dense light- to medium-gray cliff-forming flows.

The andesites are notable for well-developed felty textures and reaction relations betwen phenocrysts and the groundmass. The flow-alined plagioclase laths of the groundmass neatly surround the phenocrysts, which have been rotated into the flow planes together with flattened and collapsed vesicles.

The phenocrysts occur singly or in glomeroporphyritic clots and show clear evidence of reaction with the groundmass material. Plagioclase phenocrysts are commonly sieved with small crystals of mafic minerals and have corroded outer margins. Olivine and subcalcic augite phenocrysts have thin selvages of augite with or without magnetite granules. Flat-stage optical data suggest the presence of both subcalcic and calcic augite as phenocrysts and groundmass minerals in most of the basaltic andesites, as in many other rocks from the Mount Edgecumbe volcanic field.

One basaltic andesite (61ALy567a) was analyzed chemically (column 5, table 2), and comparison of its analysis and norm with Nockolds' (1954) average andesite suggests that the rock is an andesite, although the mode shows basaltic affinities.

FIGURE 6.—Aerial view of Mount Edgecumbe from the southeast. Light-colored lapilli and ash on upper unforested flanks are underlain by outward-dipping lava and tuff layers. Photograph by U.S. Navy.

Dacite and possible dacite.—The composite cone of Mount Edgecumbe consists of alternating meter-thick dacite flows and airfall tuff layers here called the "dacite" unit. The deposits around the former vent at Crater Ridge are probably similar and are here referred to the "possible dacite" unit. The "possible dacite" is known only from aerial observation and from a few thin sections of specimens collected at unspecified localities by F. E. Wright in 1904; the available field and petrographic evidence supports their temporal and compositional similarity to the deposits of Mount Edgecumbe.

The Mount Edgecumbe dacite flows and airfall tuff deposits are well exposed on the rim of the summit crater (figs. 4 and 6), where they dip outward from a point close to the northwest part of the rim. Many individual lava and tuff units are present; in general, the purplish-gray-weathering airfall tuff layers predominate over the medium-gray-weathering flows. The lava flows are slightly vesicular, porphyritic augite dacites and hypersthene-augite dacites characterized by well-developed flow features, including vesicle trains, and by oxidized flow tops.

The alternating lava flow and tuff layers are mantled on the outer slopes, and locally within the summit crater, by the distinctive yellow and orange "lapilli and ash" unit; they are intruded by a small quartz latite(?) dome on the northwest rim near the apex of the projected layers. The sides of the summit crater are obscured by rubble and talus in many places (fig. 8).

Some petrographic features of a typical dacite from Mount Edgecumbe cone are summarized in table 1. Other notable features include broken phenocrysts of zoned plagioclase that show blotchy alteration to a claylike mineral. Optical properties suggest that both orthopyroxene and clinopyroxene (augite and subcalcic augite) are present.

The rock looks like an andesite, on the basis of color, hyalopilitic groundmass texture, and general contrast with the basalts. However, a chemically analyzed sample (62ABd446; column 7, table 2) is a dacite by comparison with Nockolds' (1954) averages.

Quartz latite domes.—The dacitic lava flows and tuff layers of Mount Edgecumbe and Crater Ridge were intruded by two viscous steep-sided quartz latite domes.

The largest of these masses covers about 6.5 sq km on Crater Ridge (fig. 7) and the hills directly east of the ridge. It consists of locally vesicular or amygdaloidal, gray- and reddish-brown-weathering aphanitic, augite-bearing quartz latite. The detailed internal structure of this vertically flow-layered dome is not known, but it is probably a composite of at least three contiguous masses which rose more or less synchronously. The

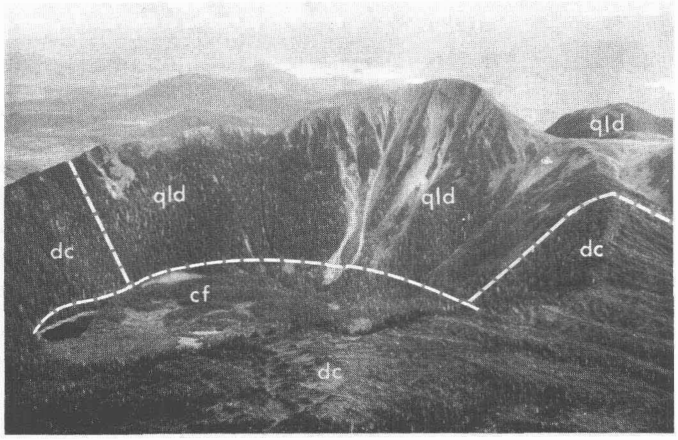

FIGURE 7.—Crater Ridge and Crater Ridge caldera viewed from Mount Edgecumbe, Kruzof Island, southeastern Alaska. The quartz latite dome (qld) makes up all but the left-hand part of Crater Ridge. Possible dacite unit (dc) and caldera fill unit (cf) shown also. Shell Mountain and other cinder cones are visible in the distance beyond the ridge.

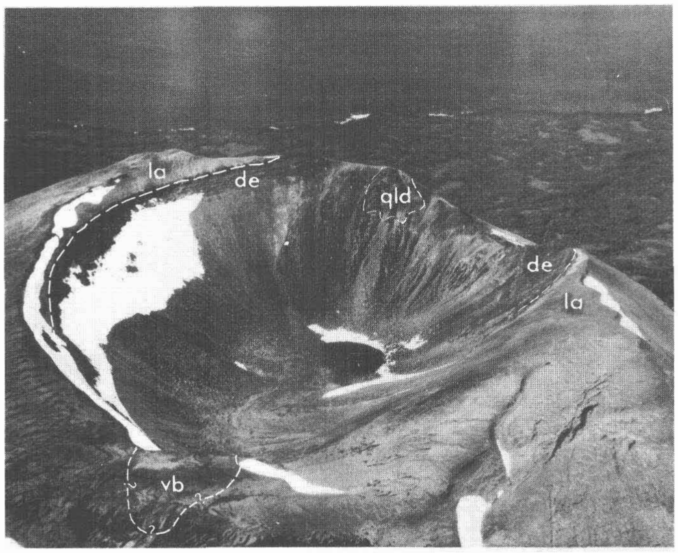

FIGURE 8.—Aerial view of summit crater of Mount Edgecumbe, Kruzof Island, southeastern Alaska, from the southeast. The crater is filled largely by colluvium derived from the dacite and tuff layers which form the cone. "Lapilli and ash" unit (la) at left and right overlies "dacite" unit (de), which is intruded by quartz latite(?) (qld) at right center. Possible vent breccia (vb) is exposed in a small area. Photograph by U.S. Navy.

domal complex probably was about 0.65 sq km larger before collapse of the Crater Ridge caldera.

A second quartz latite dome forms a gray-weathering outcrop about 300 m in diameter on the west-northwest rim of Mount Edgecumbe (fig. 8). It clearly truncates the radially dipping tuff and lava-flow deposits of the composite cone. The attitudes of these deposits suggest that their vent was close to, and may be plugged by, the dome.

The quartz latite contains only a few percent of plagioclase and other phenocrysts in a felty groundmass (table 1). The material surrounding the alined plagioclase laths of the groundmass is anisotropic, probably devitrified glass. The banding in the quartz latite is caused by streaks and irregular splotches of hematite and, to a lesser extent, opaque minerals more or less parallel to the flow alinement in the groundmass.

Comparison of a chemical analysis (table 2, column 9) and norm with those of the average dellenite (quartz latite), rhyodacite, and rhyolite obsidian of Nockolds (1954) suggests that the rock is a quartz latite or a rhyodacite.

Dacite flows and associated cinder cones.—The "basaltic andesite" unit on the southwestern tip of Kruzof Island is overlain by about 13 sq km of cliff-forming dacite flows, which crop out continuously from near Engano Point to beyond Sitka Point. The exposures are best visited at low tide because the surf breaks against the sea cliffs at all other times.

The lower part of the unit includes medium-dark-gray and grayish-brown, strikingly layered flows; its upper part is made up of dense reddish-gray flows and minor breccia and tuff. Some of the dense flows and breccias were deposited on an irregular (erosional?) surface cut across the layered flows.

All four rock specimens studied in thin section contain a few percent of corroded plagioclase phenocrysts, and accompanying phenocrysts of augite and hypersthene have narrow reaction zones. Perhaps the most striking microscopic feature of these rocks is the presence of abundant microphenocrysts intermediate in size (and, for plagioclase, intermediate in composition) between phenocrysts and groundmass minerals. The microphenocrysts are generally well alined in a felty texture, and groundmass plagioclase laths are also well alined in some specimens.

The specimens studied were classified as nonvesicular porphyroaphanitic hypersthene-bearing augite andesites or trachyandesites on the basis of their microscopic features (table 1), but comparision (table 2, column 8) with Nockolds' (1954) average suggests a dacitic composition.

Older unsampled flows and associated cinder cone.—About 20 sq km of gentle terrain southeast and east of Shell Mountain was mapped photogeologically as "older unsampled flows and associated cinder cone" (fig. 4). The unit has a shieldlike form and appears to have been erupted from near a partly dissected cinder cone. The unit is interpreted to rest on the "oldest basalt flows" and "basalt and breccia" units, and it may be constrained on the southwest by "possible dacite" flows which emanated from Crater Ridge.

Caldera fill and crater subsidence deposits.—The deposits partly filling the caldera at Crater Ridge and the summit crater of Mount Edgecumbe are poorly known. The Mount Edgecumbe crater appears to be filled mostly by colluvium derived from the crater walls (fig. 7). The debris in Crater Ridge caldera was described by F. E. Wright (unpub. notes, 1904) as a jumble of great angular blocks of lava, and the mound near the north wall of the caldera was described as consisting of blocks of slightly scoriaceous lava 0.9–9.0 m in diameter. Wright described the caldera floor as swampy in places and noted that the shallow lake on the west side bubbled locally at irregular intervals. The bubbles are of nonflammable gas according to Wright and are definitely not marsh gas.

The caldera of Crater Ridge in particular is worth further study. As shown on figure 4, it is 1.6 km in diameter at the rim, 1.1 km in average diameter at the floor, and about 240 m deep. The volume is calculated to be 1.4 cubic kilometers. Truncation of the quartz latite dome by the caldera suggests that it formed by collapse, but conclusive evidence is lacking. Figure 5 and the explanation of figure 4 reflect the inexact dating of the caldera formation. Our reconnaissance data do not provide the age relation between the "lapilli and ash" unit and the formation of the caldera.

Vent breccia.—A small area on the southeast rim of Mount Edgecumbe is underlain by glassy volcanic breccia which truncates the layered deposits of the cone (figs. 4 and 8). The breccia is interpreted to fill a vent. It is reddish-brown weathering, contains about 25 percent angular, 0.2–5-cm-long fragments of dacite(?) and vesicular porphyroaphanitic hypersthene-augite dacite in a flow-banded, dark-red and black glassy matrix. About 10 percent of the rock consists of angular voids.

The one specimen studied in thin section (table 1) is a clast in the vent breccia and is somewhat similar to the dacitic rocks from elsewhere on Mount Edgecumbe. It is notable mainly for its high content (10 percent) of hypersthene phenocrysts, the presence of plagioclase microphenocrysts in addition to the groundmass and phenocrystic plagioclase, and the reaction relations around hypersthene and plagioclase phenocrysts.

In addition to the rock fragments, the glassy breccia matrix also encloses scattered small (less than 1 mm) plagioclase phenocrysts of about An_{37} composition.

Lapilli and ash.—The distribution of the "lapilli and ash" unit shown in figure 4 is misleading because the only outcrop areas shown are the most conspicuous ones noted. Probably almost all the volcanic field and adjacent basement rock areas are or were mantled by this unit; large areas of unknown size inland from the south and east shores of the island are known to have a thick ash blanket.

The lapilli and ash deposits noted during the mapping range from zero to 5–6 m in thickness on the lower parts of the island and may be more than 15 m thick on the higher parts of Mount Edgecumbe (fig. 7).

The lapilli and ash weather reddish orange and yellowish brown at different localities and consist almost entirely of siliceous pumice and (or) scoria with less than 5 percent phenocrysts and lithic fragments. The two specimens studied in thin section (table 1) are very vesicular glassy rocks with minor content of plagioclase and pyroxene crystals and lithic fragments. The refractive index of the glass is about 1.51 to 1.52, indicating a silica content of 65 to 68 percent according to the general curve of Huber and Rinehart (1966). Hence the rocks may be dacites.

Young and younger unsampled cinder cones and flows.—The two youngest volcanic units shown on figure 4 are known only from aerial photographs and distant aerial observations. The "young unsampled cinder cones" making up Shell Mountain and nearby smaller cones are distinguished from other, apparently older cones by their undissected forms. As interpreted, all the young cones rest on the "oldest basalt flows" unit and one also apparently overlaps onto the "possible dacite" unit of Crater Ridge.

The "younger unsampled flows and associated cinder cones" were mapped separately because they are undissected and are not covered by thick vegetation, as are all the other volcanic units.

Alluvium

The areas shown on figure 4 as "alluvium" are broad valleys filled with sand and gravel of probable local derivation. These areas were not examined in detail, and it is probable that many are underlain at shallow depths by the "lapilli and ash" unit.

PETROGENESIS

The Mount Edgecumbe volcanic field is nearly ideal for the study of petrogenetic relationships within a single magma series for the following reasons: (1) there is wide variation of rock type, from basalt containing 48 percent SiO_2 to quartz latite containing almost 70 percent SiO_2; (2) the relatively short duration of activity and the clear temporal separation from earlier magmatic activity (that is, the mesozonal intrusions of middle Tertiary time) obviate many interpretive problems that can arise in a complex area such as the Cascade Range (Hopson and others, 1967); (3) the geographic isolation from other Holocene volcanic centers eliminates problems of mixing or contamination with other magma series; and (4) the geomorphic features are varied and well preserved and consequently are useful in establishing stratigraphic succession.

The reconnaissance nature of our fieldwork and the lack of precise determinations of phenocryst and groundmass compositions preclude setting up a detailed petrologic model for the Mount Edgecumbe volcanic field. However, the available data do permit a few tentative conclusions and a comparison with other volcanic series.

The chemical analyses (table 2) define a relatively smooth compositional trend (figs. 9 and 10) that we interpret as reflecting differentiation in a subjacent magma chamber. The trend from basalt to quartz latite also correlates with sequence of eruption, as

TABLE 2.—*Chemical analyses and CIPW norms of specimens from the Edgecumbe Volcanics, Kruzof Island, Alaska*

[Analyses 1 and 3–7 by P. L. D. Elmore, S. D. Botts, Lowell Artis, D. Taylor, G. W. Chloe, H. Smith, and J. L. Glenn using rapid-rock techniques (Shapiro and Brannock, 1962) supplemented by atomic absorption. Analyses 2, 8, and 9 by A. C. Bettiga using X-ray spectroscopy for SiO_2, Al_2O_3, CaO (Nos. 8 and 9 only), TiO_2, MnO, and total iron, by L. B. Beatty using wet chemistry for FeO, MgO (No. 2 only), CaO (No. 2 only), Na_2O, K_2O, H_2O+, H_2O-, P_2O_5, and CO_2, and by R. E. Mays using quantitative spectrographic analysis for MgO (Nos. 8 and 9 only)]

Number	1	2	3	4	5	6	7	8	9
Chemical analysis									
SiO_2	48.0	50.0	51.3	52.6	53.8	56.7	59.5	60.4	69.5
Al_2O_3	17.3	17.4	18.1	18.4	18.1	17.7	17.5	16.9	15.2
Fe_2O_3	2.1	2.3	2.0	2.8	1.5	1.0	1.2	1.8	3.2
FeO	6.5	6.2	6.1	5.5	6.1	6.2	4.7	4.9	.33
MgO	9.6	7.1	6.5	5.6	5.2	4.2	3.6	2.6	.42
CaO	11.0	10.8	10.2	9.0	9.1	7.0	6.8	5.5	2.3
Na_2O	2.5	3.4	3.3	3.4	3.8	3.5	4.2	4.8	5.0
K_2O	.13	.20	.25	.47	.40	1.3	.81	1.2	2.1
H_2O-	.77	.12	.10	.12	.04	.08	.09	.05	.25
H_2O+	1.0	.26	.51	.48	.26	.64	.39	.07	.85
TiO_2	.79	1.1	1.1	1.1	.98	1.1	.74	.96	.32
P_2O_5	.13	.30	.34	.35	.39	.40	.32	.37	.10
MnO	.17	.18	.16	.16	.16	.15	.12	.13	.12
CO_2	<.05	<.05	<.05	<.05	<.05	<.05	<.05	.06	<.05
Total	100	99.4	100	100	100	100	100	99.7	99.7
Specific density:									
Powder	2.94	--------	2.91	2.88	2.89	2.78	2.78	--------	--------
Bulk	2.88	--------	2.50	2.60	2.63	2.69	2.48	--------	--------
CIPW norms									
Q			0.1	3.5	2.6	7.9	11.1	11.4	27.2
C									.9
or	0.8	1.2	1.5	2.8	2.4	7.7	4.8	7.1	12.4
ab	21.2	28.8	27.9	28.8	32.2	29.6	35.5	40.6	42.3
an	35.6	31.6	33.8	33.6	31.1	28.7	26.5	21.0	10.4
wo	7.4	8.2	5.9	3.5	4.6	1.3	2.0	1.4	--------
en	11.6	11.0	16.2	13.9	13.0	10.5	9.0	6.5	1.0
fs	4.5	5.0	8.0	6.3	8.6	9.0	6.6	6.2	--------
fo	8.6	4.7	--------	--------	--------	--------	--------	--------	--------
fa	3.7	2.3	--------	--------	--------	--------	--------	--------	--------
mt	3.0	3.3	2.9	4.1	2.2	1.5	1.7	2.6	.5
il	1.5	2.1	2.1	2.1	1.9	2.1	1.4	1.8	.6
ap	.3	.7	.8	.8	.9	.9	.8	.9	.2
cc	<.1	<.1	<.1	<.1	<.1	<.1	<.1	.1	<.1
Total	98.3	99.0	99.3	99.5	99.6	99.3	99.5	99.6	98.6
di	14.3	15.9	11.5	6.9	9.1	2.5	4.0	2.9	--------
hy	9.2	8.3	18.6	16.9	17.2	18.2	13.7	11.2	1.0
ol	12.3	7.0	--------	--------	--------	--------	--------	--------	--------

1. 61ABg734a. Olivine-pigeonitic augite basalt from "Basalt and breccia" unit.
2. 61ABd720. Porphyritic olivine-bearing augite basalt from "Oldest basalt flows" unit.
3. 61ABd725b. Microporphyritic olivine basalt from "Oldest basalt flows" unit.
4. 61ALy566. Microporphyritic augite-olivine basalt from "Oldest basalt flows" unit.
5. 61ALy567a. Porphyritic olivine-bearing pigeonite basaltic andesite from "Basaltic andesite" unit.
6. 61ALy571. Porphyritic hypersthene basaltic(?) andesite from "Andesite" unit.
7. 62ABd446. Porphyritic augite dacite from "Dacite and possible dacite" unit.
8. 61ABd723d. Porphyritic pyroxene dacite from "Dacite flows and associated cinder cones" unit.
9. 62ABd444. Porphyritic augite-bearing quartz latite from "Quartz latite domes" unit.

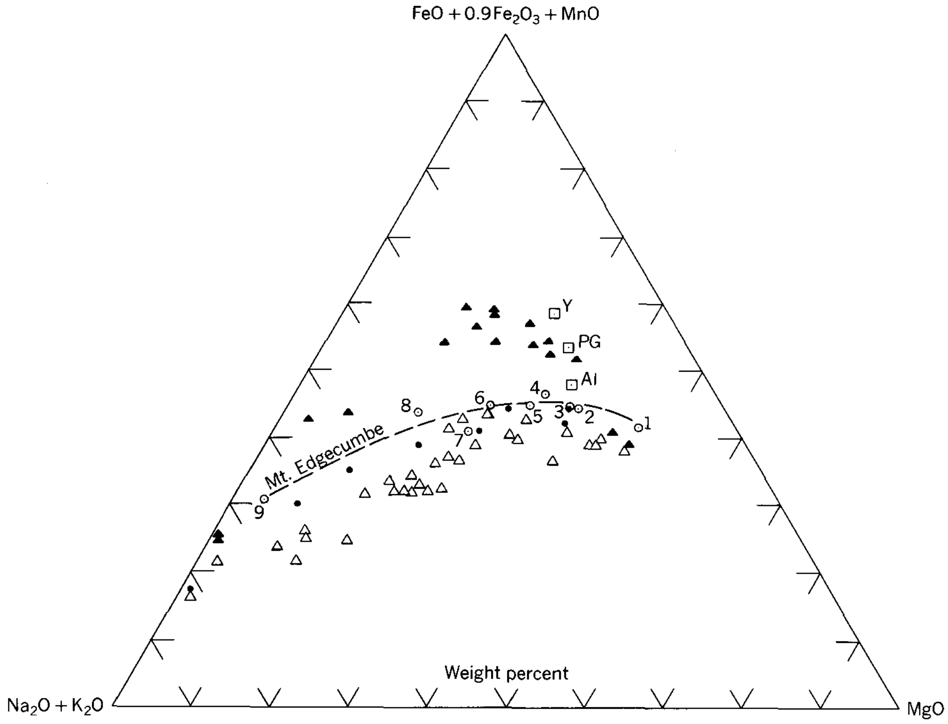

FIGURE 9.—AFM diagram comparing Mount Edgecumbe rocks with selected volcanic rocks from the Pacific coast of North America. Open circles, Mount Edgecumbe (numbers refer to columns of table 2). Closed circles, Mount Jefferson (Greene, 1968). Open triangles, Mount Lassen (Williams, 1932). Closed triangles, aphyric lavas and groundmasses, northeastern Umnak Island, Aleutian Islands, Alaska (Byers, 1961). Open squares, magma types of Waters (1962); Y, Yakima type; PG, Picture Gorge type; Al, high-alumina type from the Oregon Plateaus and Cascade Range.

deduced from the field criteria (fig. 5). The younger rocks are closer to the AF side of the AFM diagram (fig. 9) and richer in silica (fig. 10). The apparent exception is No. 1, the basalt lowest in silica and highest in MgO. If the admittedly tentative stratigraphic assignment is correct (p. D7), this sample was extruded later than the "oldest basalt flows" (samples 2, 3, and 4, table 2).

Many of the analyzed specimens from the Mount Edgecumbe field are porphyritic, and, as Bowen (1956) has emphasized, the composition of a porphyritic rock may or may not represent the composition of a liquid, depending on the gain or loss of crystals during crystallization. Smooth variation on diagrams such as figures 9 and 10 is commonly taken to indicate close approximation of the rocks to liquids. Efforts to correct the Mount Edgecumbe chemical data for phenocryst content, by use of data from table 1, scattered the data points and considerably distorted the simple AFM variation of the uncorrected analyses. We therefore conclude that the porphyritic rocks closely approximate a liquid.

The chemical variation displayed by the Mount Edgecumbe series is similar to that displayed by many

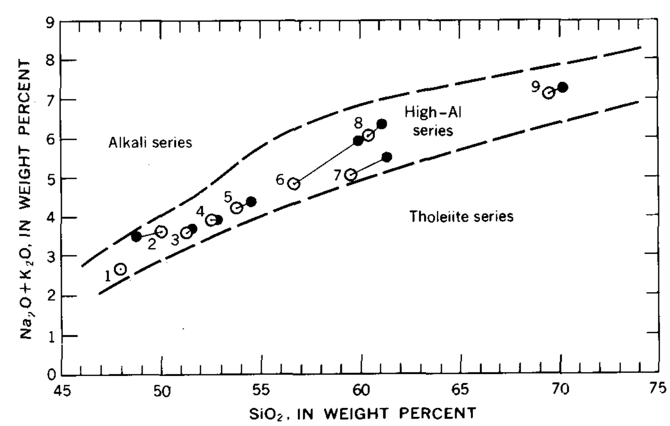

FIGURE 10.—Variation of Na_2O+K_2O with SiO_2 in the Edgecumbe volcanic series. Open circles, Na_2O+K_2O uncorrected for phenocrysts. Closed circles, composition of groundmass as calculated by subtraction of phenocrysts. Dashed lines are boundaries of magma series of Kuno (1965). Numbers refer to columns of table 2.

circum-Pacific volcanic suites (fig. 11). The alkali-lime index of the Mount Edgecumbe series is 60–61, thus falling within the calc-alkalic subdivision of Peacock (1931). This index is lower than that of the calcic High Cascades magma series (61–64), but higher than that of the calc-alkalic Oregon Plateaus series (55–58; LeMasurier, 1968).

The variation curve of the Mount Edgecumbe series in the AFM diagram shows a relative low iron content that is characteristic of calc-alkaline volcanic series (Nockolds and Allen, 1953) (fig. 9). The data suggest that the various calc-alkaline series plotted in figure 9 differ systematically in Fe/Mg+alk ratio, the Lassen series having the smallest ratio and the Umnak series the largest.

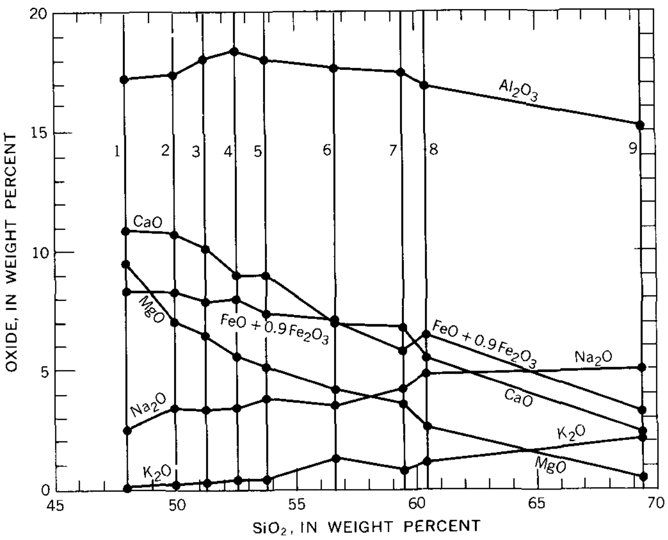

FIGURE 11.—Variation of major oxides with SiO_2 in the Edgecumbe volcanic series. Numbers refer to columns of table 2.

The differences among the series in figure 9 cannot be evaluated simply, for the various series are not comparable as to the manner in which the phenocrysts were treated in the evaluation of the raw analyses. The variation curves for Mount Lassen, Mount Jefferson, and Mount Edgecumbe are probably comparable, because they are for whole rocks, many of which are porphyritic, and have not been corrected for phenocryst content. The Umnak data, on the other hand, are from aphyric lavas or have been corrected for phenocryst content (Byers, 1961). Recalculation of the Mount Edgecumbe data for phenocryst content reduces, but does not eliminate, the difference between the Mount Edgecumbe series and the Umnak series.

Interpretation of the Mount Edgecumbe data in the framework of Kuno (1960, 1965) shows that all the analyses fall within the high-alumina basalt series (fig. 10). Correction for phenocryst content and composition (as above) shifts all the analyses within the high-alumina field. The exception, 61ABd720, is the sample rich in olivine and plagioclase phenocrysts. The basalts of Mount Edgecumbe are also compared in figure 9 with the three basalt types of Waters (1962) from the Columbia Plateau and Cascade Range in Oregon. The Edgecumbe basalts are closer to his high-alumina Cascade basalts than the Yakima and Picture Gorge Basalts of the Columbia Plateau.

The chemical correspondence of the Edgecumbe basalts to high-alumina basalt is compatible with their petrographic characteristics. However, neither the chemical nor the petrographic data indicate definitely whether the Edgecumbe basalts are alkalic basalt or whether they are tholeiite, according to the criteria of Macdonald and Katsura (1964). The "oldest basalt flows" (p. D6–D7) contain sporadic phenocrysts of olivine rimmed by grains of clinopyroxene and magnetite. This apparent reaction relationship, together with the occurrence of at least some subcalcic augite, suggests a tholeiite affinity when one uses the criteria of Macdonald and Katsura. On the other hand, the abundant groundmass olivine suggests an alkalic affinity.

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THE CHITISTONE AND NIZINA LIMESTONES OF PART OF THE SOUTHERN WRANGELL MOUNTAINS, ALASKA—A PRELIMINARY REPORT STRESSING CARBONATE PETROGRAPHY AND DEPOSITIONAL ENVIRONMENTS

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Abstract.—Carbonate petrographic and related studies of the Chitistone and Nizina Limestones in parts of the southern Wrangell Mountains, Alaska, provide new information on the depositional history, lithology, extent, and fauna of the formations. The Upper Triassic carbonates, about 3,500 feet in maximum thickness, disconformably overlie the Nikolai Greenstone and conformably underlie the McCarthy Formation. Beds of the Chitistone Limestone reflect intertidal and supratidal conditions followed by low-energy restricted shallow-water marine deposition interspersed with high-energy shoaling-water deposition. Carbonates of the overlying Nizina Limestone formed in deeper water on the basinal slope of the drowned Chitistone carbonate platform and, during the later stages, on shallow carbonate shelves. A rapid rise in sea level terminated the carbonate deposition. Inferences on the depositional environments are corroborated by the distribution and nature of the fossils. Possibly the large Kennecott copper deposits in the lower part of the Chitistone Limestone are genetically related to thermal brines associated with the intertidal-supratidal rocks.

This report stresses petrographic studies that were made to clarify the depositional history of the Late Triassic Chitistone and Nizina Limestones. These two limestone formations are exposed intermittently throughout a northwest-trending belt about 65 miles long and 15 miles wide along the southern flank of the Wrangell Mountains (fig. 1), Alaska.

The investigations included measuring and sampling six stratigraphic sections as well as relevant laboratory studies by Armstrong, quadrangle mapping and related studies of the southern Wrangell Mountains under the direction of MacKevett, and biostratigraphic studies in the field and laboratory by Silberling. The investigations are considered to be preliminary inasmuch as only parts of the carbonate terrane were sampled and studied extensively.

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The carbonate rocks studied in most detail form bold outcrops on the east side of Green Butte in the McCarthy B-5 and C-5 quadrangles (figs. 1 and 2). Other exposures carefully studied are located (1) near Boulder Creek in the McCarthy B-4 quadrangle, (2) northeast of Nikolai Creek in the McCarthy B-5 quadrangle, (3) near the Kennecott mines in the McCarthy C-5 quadrangle, (4) south of Hidden Creek in the McCarthy C-6 quadrangle, and (5) south of the Kuskulana Glacier in the McCarthy C-7 quadrangle (fig. 1).

About 200 thin sections and numerous sawed and polished rock samples were examined in the laboratory. Calcite-dolomite ratios were determined by staining with alizarine red S, using the method described by Friedman (1959).

The main objectives of the investigations were (1) to describe the carbonate petrography of the Chitistone and Nizina Limestones, (2) to determine their depositional environments and possibly document the carbonate depositional cycles, (3) to ascertain possible relationships between the carbonate rocks and the localization of the Kennecott copper lodes, and (4) to compare the carbonate rocks with other ancient and modern carbonate sequences. The classification of carbonate rocks used in this report is from Dunham (1962) and is shown in table 1.

Additional information on the distribution and general properties of the Chitistone and Nizina Limestones may be found in reports by Moffit (1938) and MacKevett (1963, 1965a, 1965b, and 1969). The sequence and age of some of the more diagnostic fossils from the Triassic rocks of the Wrangell Mountains are summarized in a report by Silberling and Tozer (1968, p. 48).

The sedimentary features and structures used to delineate intertidal and supratidal facies are described

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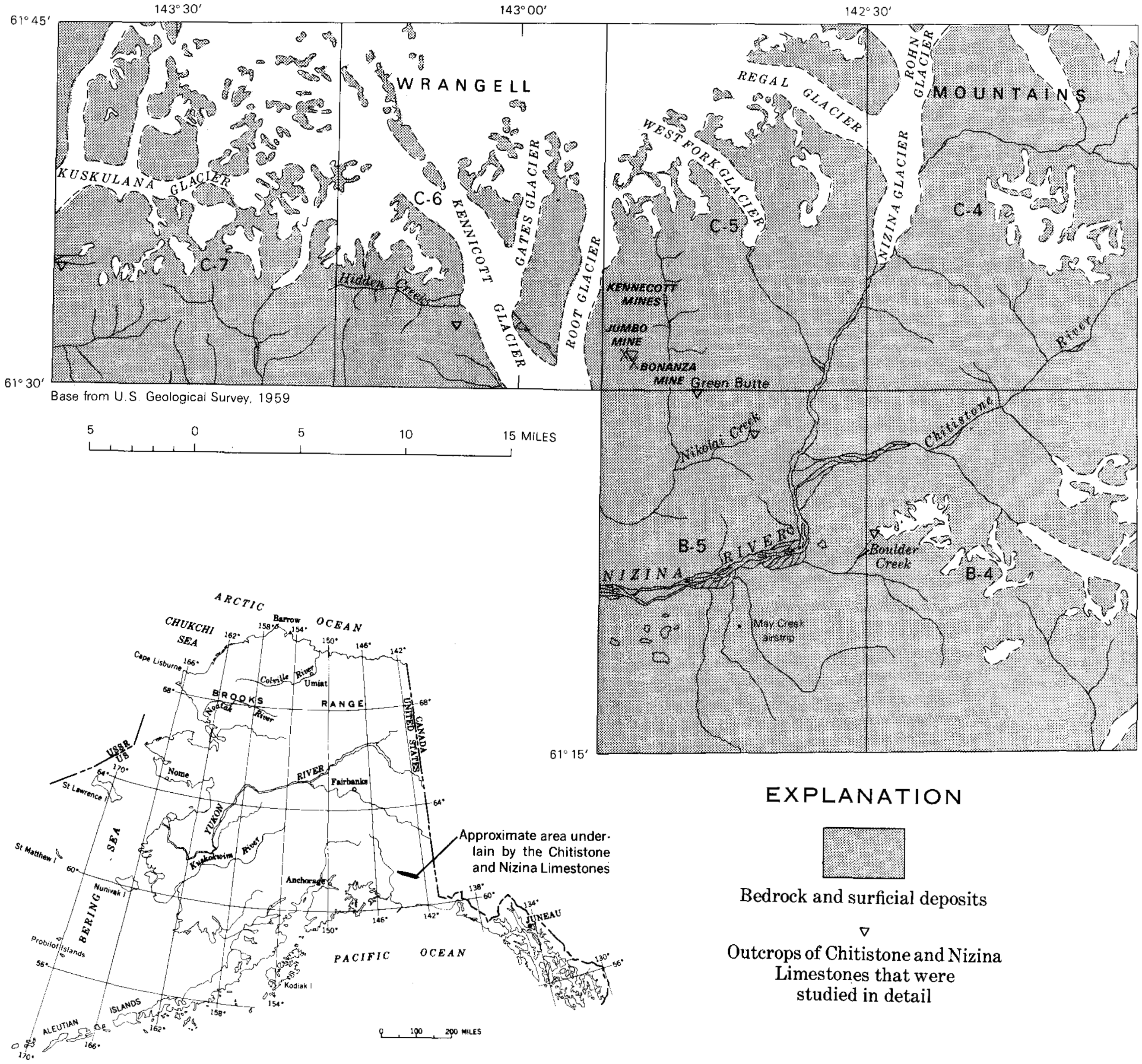


FIGURE 1.—Map of Alaska showing the approximate area underlain by the Chitistone and Nizina Limestones, and map of part of the McCarthy 1° by 3° quadrangle showing locations of the carbonate rocks studied.

in detail by Fischer (1964), Logan, Rezak, and Ginsburg (1964), Shinn, Ginsburg, and Floyd (1965), Illing, Wells, and Taylor (1965), Roehl (1967), Wilson (1967c), and Shinn (1968a); sedimentary and textural features used to define shallow marine and shelf carbonates are described by Purdy (1963), Ball (1967), and Wilson (1967a, 1967b); and the criteria for toe-of-the-slope and basinal sediments are described by Wilson (1967c) and McDaniel and Pray (1967). Detailed descriptions of these sedimentary features and how they are formed are not given in this report; the interested reader is referred to the publications listed above for details.

GENERAL DESCRIPTION AND RELATIONS

The Chitistone and Nizina Limestones form a stratigraphic sequence about 3,500 feet in maximum thickness along the southern flank of the Wrangell Mountains (fig. 1). Rohn (1900, p. 425) named the rocks of this Upper Triassic sequence the Chitistone Limestone, but subsequently Martin (1916, p. 693) applied the name Nizina Limestone to the generally thinner bedded

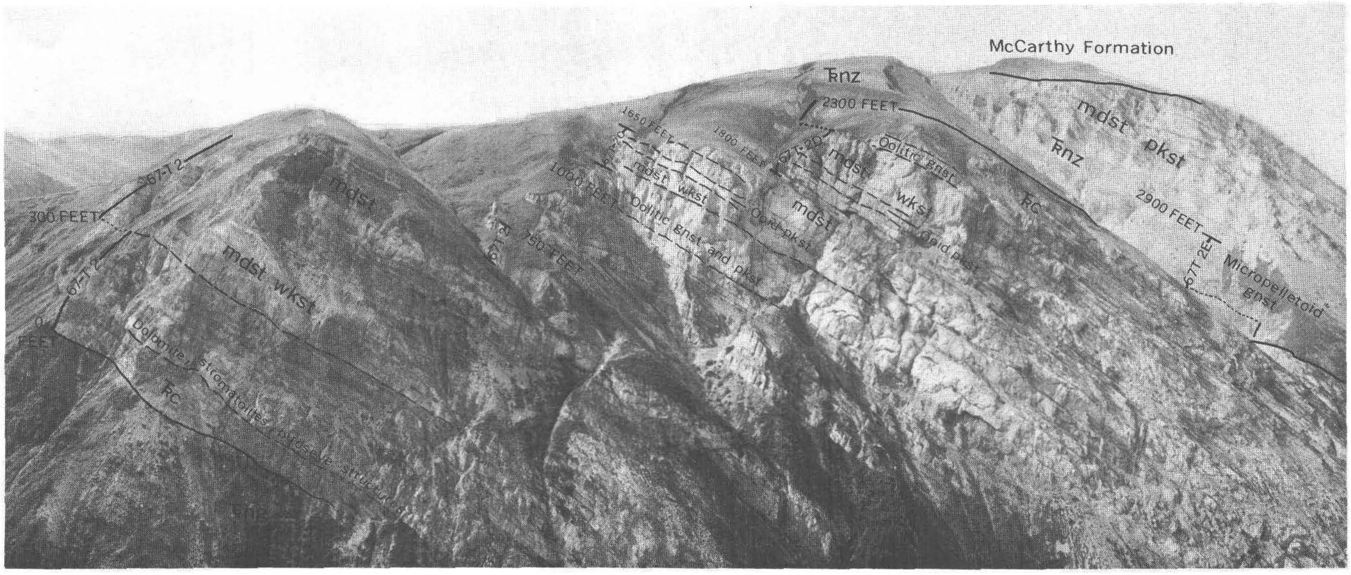


FIGURE 2.—Photograph of the east face of Green Butte. Locations of the measured and sampled sections shown on figure 8 are indicated by black lines and section numbers. Contact between Chitistone Limestone and the underlying Nikolai Greenstone is shown on left-hand side. Triassic carbonate section is about 3,500 feet thick. Classification of carbonate rocks is from Dunham (1962) and is shown in table 1. T̄Rng, Nikolai Greenstone; T̄Rc, Chitistone Limestone; T̄Rnz, Nizina Limestone; mdst, Lime mudstone; wkst, wackstone; pkst, packstone; gnst, grainstone.

TABLE 1.—*Classification of carbonate rocks according to depositional texture*

[From Dunham, 1962, p. 117]

Depositional texture recognizable					Depositional texture not recognizable
Original components not bound together during deposition				Original components were bound together during deposition . . . as shown by intergrown skeletal matter, lamination contrary to gravity, or sediment-floored cavities that are roofed over by organic or questionably organic matter and are too large to be interstices.	Crystalline carbonate (Subdivide according to classifications designed to bear on physical texture or diagenesis.)
Contains mud (particles of clay and fine silt size)			Lacks mud and is grain supported.		
Mud supported		Grain supported.			
Less than 10 percent grains.	More than 10 percent grains.				
Mudstone	Wackestone	Packstone	Grainstone	Boundstone	

and darker rocks that constitute the upper part of the sequence. The thickness of the entire carbonate sequence and its two constituent formations differs widely; generally the Chitistone Limestone is the thicker of the two units. The Chitistone Limestone disconformably overlies the Nikolai Greenstone of late Middle and (or) early Late Triassic age. At some places the top of the greenstone is marked by a weathered zone a few inches thick. Contacts between the Chitistone and the overlying Nizina Limestone generally are broadly gradational, but locally, as near Green Butte (fig. 7), they are sharp. The Nizina Limestone is conformably overlain by the McCarthy Formation of Late Triassic and Early Jurassic age.

The Chitistone Limestone commonly consists of bedding units between 2 and 20 feet thick that form bold cliffs marked by a few caves and related solution cavities. It is mainly light, medium, or olive gray on both fresh and weathered surfaces and consists of limestone with subordinate dolomite and a few chert nodules.

The Nizina Limestone consists of limestone with subordinate chert lenses and nodules and rare grains of dolomite. Characteristic beds of the Nizina Lime-

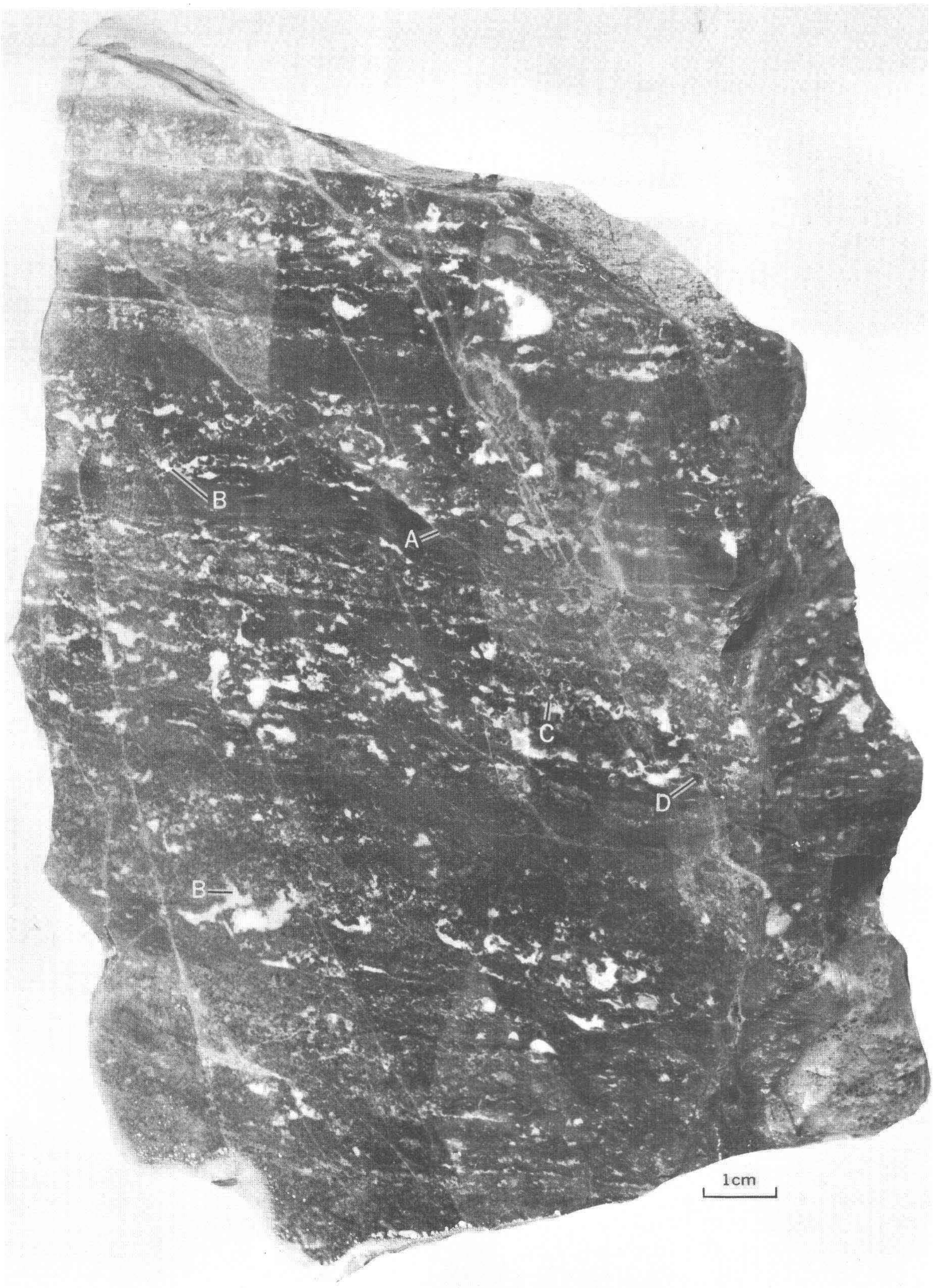


FIGURE 3.—Dolomitic lime mudstone with algal mat chips (*A*), vugs and birdseye structures (*B*), pellets (*C*), and clasts (*D*). Collected 190 feet above the base of the Chitistone Limestone, Nikolai Creek. Shinn, Ginsburg, and Lloyd (1965, p. 119, fig. 7) illustrate a specimen similar to this from the Holocene intertidal zone of Andros Island, Bahamas.

stone range from ½ to 3 feet in thickness. They form bold outcrops but generally are more subdued than the cliffs of the Chitistone Limestone. Most of the Nizina Limestone is medium or dark gray when fresh and diverse shades of brown when weathered.

Mapping in the McCarthy B-4 quadrangle (E. M. MacKevett, Jr., and James G. Smith, unpublished data) and in the McCarthy A-4 quadrangle (Miller and MacColl, 1964), as well as supplementary paleontologic studies of the meager fauna by Silberling, indicates that contacts between the Chitistone and Nizina Limestones and between the Nizina Limestone and the McCarthy Formation transgress time boundaries.

CARBONATE PETROGRAPHY AND SEDIMENTARY STRUCTURES

Detailed petrographic studies of the Chitistone and Nizina Limestones provide information on the sedimentary history of the carbonate rocks. Much information can be deduced by comparing their properties with those of other carbonate sequences that have been studied in detail.

The basal Chitistone Limestone is marked locally by a layer of yellowish-weathering shaly limestone between 1 and 4 inches thick that is overlain by a 1- to 3-foot-thick argillaceous lime mudstone with numerous worm-tube casts and trails. Where the shaly limestone is absent, the argillaceous limestone forms the basal unit. Fossil-fragment and ooid packstones and grainstones overlie the lime mudstone and predominate throughout the lower 100 feet of the Chitistone Limestone (fig. 6*A*). Lime mudstone, dolomitic mudstone, and dolomite composed of rhombs between 100 and 200 microns long are the dominant rocks throughout the 100- to 300-foot section above the base of the Chitistone Limestone (fig. 6*B*). Most of these rocks contain well-developed birdseye structures (fig. 3) like those studied by Shinn (1968a). He believed them to be restricted to intertidal and supratidal environments. These rocks also contain algal mat chips, stromatolites, and desiccated storm layers (figs. 3 and 4)—features that according to Shinn, Ginsburg, and Lloyd (1965) and Illing, Wells, and Taylor (1965) clearly indicate intertidal or supratidal environments. The sedimentary structures indicative of such environments for the 100- to 300-foot section above the base of the Chitistone Limestone are geographically widespread. They were found in almost all the carbonate sections throughout a northwest-trending belt more than 40 miles long. Parts of this section represent an extensive intertidal-supratidal carbonate facies comparable

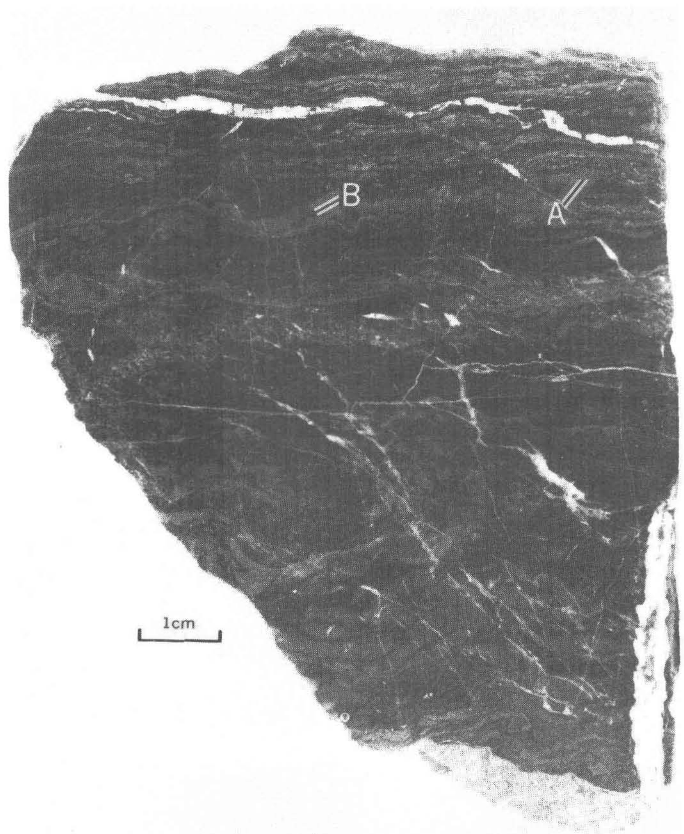


FIGURE 4.—Algal mat chips (*A*) and stromatolites (*B*) in a dolomitic lime mudstone, 270 feet above the base of the Chitistone Limestone, Boulder Creek. Sedimentary features of this specimen are similar to supratidal features shown by Illing, Wells, and Taylor (1965, p. 98, fig. 5) for Holocene cores taken from Sebkha Faishakn, Persian Gulf.

to the modern sebkha-wadi complex of the Trucial Coast of the Persian Gulf (Illing and others, 1965).

In most of the exposures studied, particularly those at Green Butte and south of Hidden Creek (fig. 1), about 300 feet of ooid packstone and echinoderm- and mollusk-rich wackestone directly overly the intertidal-supratidal rocks. These relatively high-energy packstones and wackestones indicate marine transgression. They are overlain by a sequence of 700 to 1,000 feet of clotted lime mudstone (fig. 6*C*) and wackestone that contains abraded and broken fragments of mollusks, ostracodes, and echinoderms. These rocks are gray to dark gray and occur in beds between 3 and 15 feet thick that contain about 5 percent nodular black chert. They are believd to represent shallow-water restricted marine shelf sedimentation.

Crossbedded packstone and grainstone more than 100 feet thick overlie the lime mudstone sequence in the middle part of the Chitistone section near Green Butte (fig. 5). This massive unit is composed of rounded fragments, generally between 0.4 and 1 millimeter in diameter, consisting of echinoderms, mollusks, brachio-

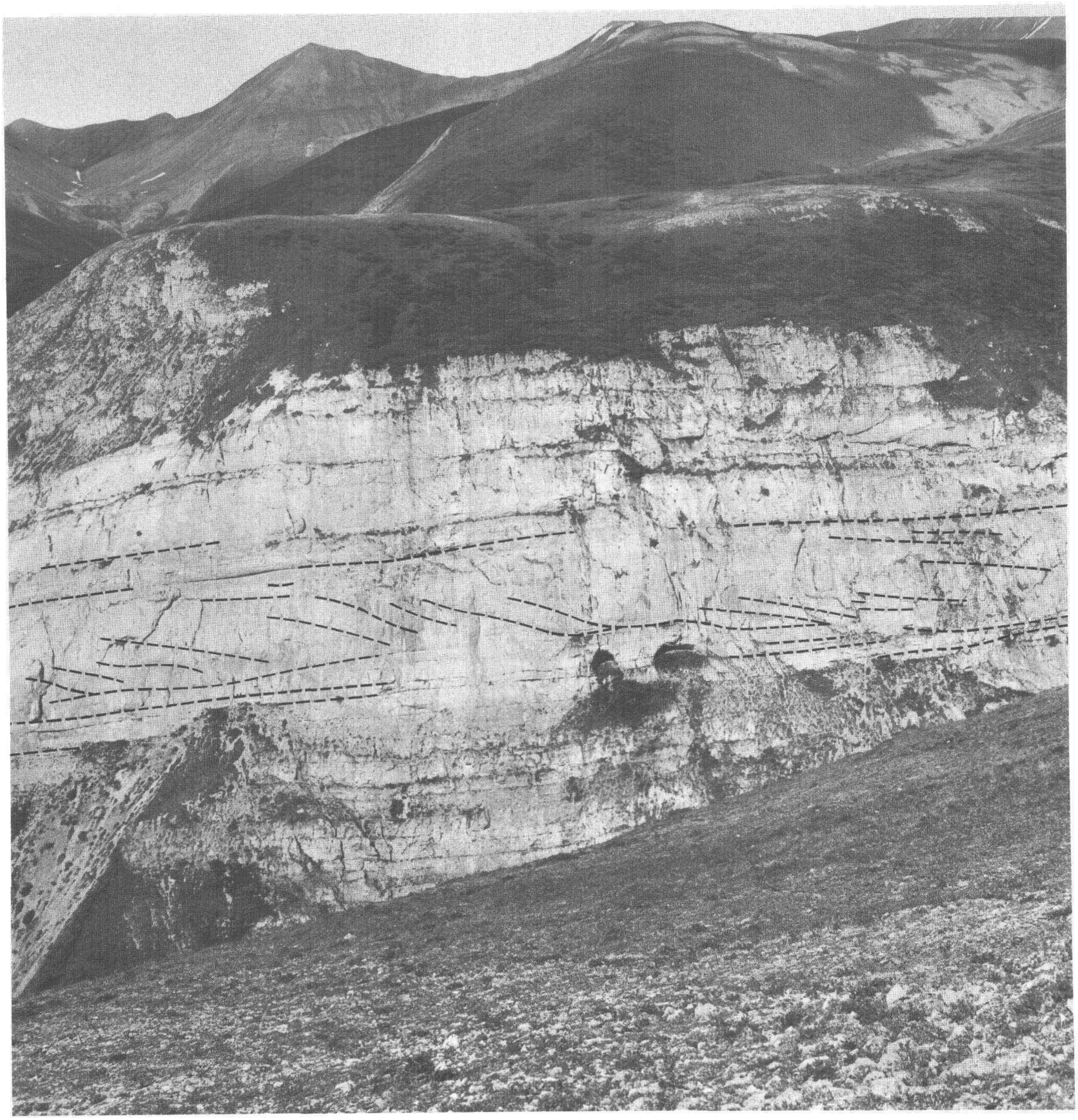


FIGURE 5.—Crossbedded oolitic grainstones, about 100 feet thick (between upper and lower dashed lines), in the central part of the Chitistone Limestone. Photograph was taken east of Green Butte. Photomicrograph of a rock specimen taken from the center of this bed is shown on figure 6*D*.

pods, calcareous algae, ooids, oolites, and large rounded lithoclasts as much as 5 mm in diameter (fig. 6*D*). On the top and bottom are horizontally stratified beds. Oolites are subordinate to rounded and sorted fossil fragments in the crossbedded sections. Except for the low percentage of oolites, the crossbedded rocks are analogous in thickness and structure to the tidal bars of calcareous sands on the modern Bahama platform that were described by Ball (1967, p. 563–571, fig. 19).

The upper part of the Chitistone Limestone above the massive crossbedded calcareous rocks is predominantly light- to dark-gray clotted lime mudstone and echinoderm-mollusk wackestone (fig. 6*E*). These beds contain three significant zones, each generally less than 100 feet thick, of packstone and grainstone (fig. 8). Two of these zones are about 200 and 400 feet above the crossbedded rocks and are composed of ooid-pelletoid-lithoclast packstone. The other zone is about 100 feet below the top of the Chitistone Limestone and consists of oolite grainstone (fig. 6*F*). All three of these zones contain grain-supported oolitic-coated particles and reflect excellent sorting—features indicative of high-energy shoaling-water depositional environments.

The lime mudstones are believed to have been deposited in shallow waters, possibly with restricted circulation, in a low-energy environment. This concept is suggested by their massive bedding and restricted fauna. Thin-section studies show that the lime mudstones are generally clotted and have undergone extensive churning by burrowing organisms (Shinn, 1968b). The massive beds of lime mudstone swell and pinch, thus suggesting that they are preserved lime mudbanks and mounds similar to those found in the shallow waters of Florida Bay. The calcareous fossil remains, with some notable exceptions, are small broken fragments, generally less than 1 mm long. The uppermost 50 feet of the Chitistone Limestone is composed of micropelletoidal grainstone.

Photographs (figs. 2 and 7) show that the lower half of the Nizina Limestone, which is mainly micropelletoidal grainstone (fig. 6*G*), contains long, lenticular, light-gray carbonate tongues. Petrographic studies show them to be lime mudstone and wackestone.

Micropelletoidal grainstones can be formed in, and are indicative of, two divergent facies. They are documented as coming from the toe-of-the-slope environment by McDaniel and Pray (1967) and Wilson (1967c) and from the open-platform environment, behind the shoaling facies and in front of the lime mudstone facies, by Wilson (1967a, p. 240, 284, pl. 3, fig. 1) and Armstrong (1967, p. 12).

An unequivocal interpretation of the environment of deposition is not possible for these pelletoidal grainstones. The writers, on the basis of field evidence, prefer the concept of a toe-of-slope environment of deposition. This preference is based on the following features: the beds are generally 6 inches to 2 feet thick, are gray in color, and contain lenticular dark-gray chert nodules and minor amounts of disseminated pyrite. The sedimentary features within the beds are small-scale crossbeds. The upper and lower surfaces of the beds may have slight undulations or oscillatory ripple marks.

Within the grainstone beds and parallel to the bedding, thin-shelled gastropods and relatively large open-sea types of pelecypods are preserved.

At Green Butte the contact between the Chitistone and Nizina Limestones is marked by pronounced lithologic and topographic changes. Thick-bedded shoaling-water lime mudstone and oolitic packstone of the Chitistone Limestone are in juxtaposition with thinner bedded, dark-gray micropelletoid grainstone of the Nizina Limestone. The present-day differences in topographic expression reflect the sharp contrast in depositional environments.

The uppermost 500 feet of Nizina Limestone near Green Butte consists predominantly of clotted lime mudstones and wackestones that contain fragments of echinoderms and mollusks. The measured section at Green Butte contains two zones of high-energy shoaling-water carbonates, each about 20 to 30 feet thick. One of the zones is about 480 feet below the top of the formation and the other about 220 feet below the top. These zones consist of grainstones and packstones that are composed of grains (0.5 to 1 mm in diameter) of rounded and coated ooids, oolites, lithoclasts, and fossil fragments including echinoderms, mollusks, foraminifers, and solenoporaceae algae. The carbonate grains are well sorted and are generally cemented by sparry calcite. The typical lime mudstone and wackestone (fig. 6*H*) of the upper part of the Nizina Limestone is dark gray and weathers brown. It forms beds between 2 and 10 feet thick and is associated with dark-gray chert nodules and lenses that are as much as 18 inches long and 5 inches thick. These rocks are believed to be the products of shallow-water shelf deposition. A 2- to 4-foot-thick bed of lime mudstone and wackestone near the top of the Nizina Limestone contains abundant disseminated pyrite and scattered echinoderm and mollusk fragments; 20 to 40 percent of the bed is black chert that forms lenses several feet long.

DEPOSITIONAL HISTORY AND CARBONATE CYCLES

Deposition of the Late Triassic carbonates commenced after a gentle widespread submergence of the continental basalt platform of Nikolai Greenstone. Early stages of the Chitistone Limestone indicate that deposition took place under widespread intertidal and supratidal conditions. Subsequently a shallow sea transgressed over the intertidal and supratidal deposits, and the bulk of the Chitistone carbonates accumulated. These rocks reflect low-energy restricted shallow-water shelf deposition interspersed with intermittent high-energy shoaling-water deposition.

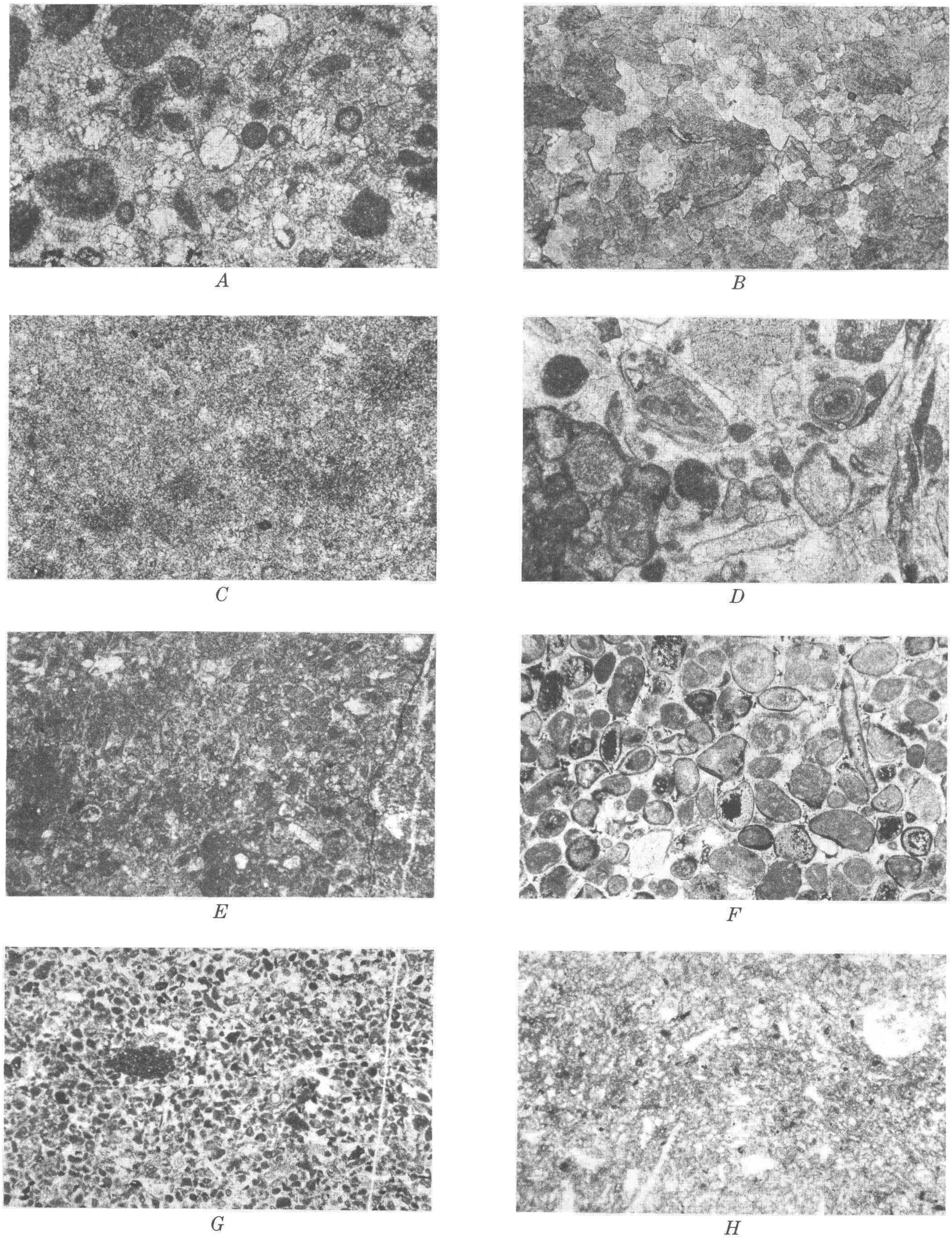


FIGURE 6.

Sedimentation of the Nizina Limestone commenced with the deposition of deeper water micropelletoid grainstone on the slope of the drowned Chitistone carbonate shelf platform. Most of the younger rocks probably were deposited in shallow- to shoaling-water environments typical of shelf carbonate deposits. Within the Nizina Limestone the shift in carbonate facies with time (figs. 2, 6*H*, 8) is believed to represent progradation of a shallow-water shelf carbonate facies over the deeper water slope carbonates of the lower part of the formation. The contact between the Nizina Limestone and the McCarthy Formation probably represents a rapid drowning of the Nizina carbonate shelf to a depth where carbonate production ceased. The dominant rocks near the base of the McCarthy Formation are dark-gray to black fissile shales and bedbed cherts. The shales are carbonaceous and contain scattered silt-size quartz grains; siliceous biogenic detritus (radiolarians and sponge spicules) are locally abundant. These are interpreted as indicating deep-water, starved basin sedimentation for the McCarthy Formation.

The Chitistone and Nizina Limestones may contain six incomplete carbonate depositional cycles (fig. 8). Five of these represent shallow-water shelf deposits formed during Chitistone time. Subsidence in general was slightly greater than carbonate production. Carbonate production clearly outstripped subsidence only during deposition of the lower 300 feet of the Chitistone Limestone; regional development of the intertidal-supratidal (sebkha-wadi complex of Illings and others, 1965) facies was the result. Carbonate cycles 2, 3, 4, and 5 represent subsidence and consist of ooid and oolite grainstones and packstones. The bases of cycles 3, 4, and 5 are lime mudstone on oolitic crossbedded grainstone (fig. 8).

The sharp contact between the Nizina and Chitistone Limestones at Green Butte marks the beginning of carbonate cycle 6. This cycle may reflect the partial drowning of the shallow-water Chitistone carbonate shelf and the deposition of micropelletoidal grainstone on a deeper water carbonate slope or apron. An alternate interpretation could be that the micropelletoid grainstone was deposited behind the shoaling-water facies and in front of the lime mud facies (figs. 8, 9).

FIGURE 6.—Photomicrographs, plane polarized light. All thin sections are from the Green Butte section. Stratigraphic location of each specimen is shown on figure 8. The suggested environment of deposition for each sample is shown in the "facies" line of figure 9. *A*, Pelletoid-ooid-echinoderm packstone. The lime mud between the particles has undergone aggrading neomorphism and is composed of 50- to 125-micron-size crystals of calcite. The specimen was collected near the Green Butte mine, 6 feet above the Nikolai Greenstone–Chitistone Limestone contact. *B*, Dolomite. Dolomite rhombs are from 200 to 400 microns in size. Specimen was collected some 230 feet above the base of the Chitistone Limestone in association with intertidal-supratidal sedimentary features. *C*, Lime mudstone with clotted pellets. The lime mudstone is composed of 5- to 10-micron-size crystals of calcite. Rare fossil fragments are ostracodes and calcispheres. This is one of the more abundant carbonate types of the Chitistone Limestone. Specimen was collected 460 feet above the base of the Chitistone Limestone. *D*, Echinoderm-mollusk-ooid-oolite-lithoclast grainstone. The specimen was collected at about the center of the crossbededd calcareous sand bed shown on figure 5. This bed is near the middle part of the Chitistone Limestone. *E*, Ostracode-echinoderm wackestones. Clotted pellets and abraded fragments of ostracodes and echinoderms suggest extensive churning by burrowing organisms. This carbonate rock type is characteristic of the upper half of the Chitistone Limestone. *F*, Ooid-oolite grainstone. Typical particles are 350 to 500 microns in diameter. Centers of the majority of ooids and oolites are composed of lime mud. Some oolites have echinoderm or mollusk fragments for centers. Specimen was collected near the top of the Chitistone Limestone. *G*, Micropelletoid grainstone. Pellets are 100 to 150 microns in diameter and have a 10- to 15-micron-thick coating. Particles also of mollusks, echinoderms, and foraminifers are present. Also present are 100- to 150-micron grains of detrital quartz. Specimen was collected 300 feet above the base of the Nizina Limestone. *H*, Echinoderm-mollusk wackestone. Clotted pellets and broken fossil fragments suggest extensive burrowing. Specimen was collected 125 feet from the top of the Nizina Limestone.

MEGAFOSSILS

In addition to providing a means of dating the Chitistone and Nizina Limestones, the nature and occurrence of invertebrate megafossils in these formations tend to confirm their sedimentary history.

In this part of the Wrangell Mountains, calcareous megafossils are virtually absent in the basal few hundred feet of the Chitistone—the intertidal deposits. In the higher parts of the Chitistone that are interpreted as open to restricted platform deposits, megafossils are scarce, even though comminuted shelly debris forms a substantial proportion of the carbonate rock. Bottom-dwelling organisms are represented mainly by sporadic and isolated gastropods and ostreid pelecypods. Ammonites, mostly arcestids and haloritids, associated with the shells of halobiid pelecypods are also found in this part of the section, but in stratigraphically restricted concentrations. All these mollusks are free-swimming, floating, or attached-floating organisms that inhabited the open sea, and their occurrence suggests the occasional influx of normal marine waters into the restricted and inhospitable environment of the shelf platform. A fauna of this kind, comprising *Tropites* cf. *T. welleri* Smith, *Arcestes*, and *Halobia* cf. *H. superba* Mojsisovics, was collected about 500 feet above the base of the Chitistone at Green Butte (USGS Mesozoic loc. M1707) and is indicative of a late Karnian age.

By far the most fossiliferous rocks of the Chitistone-Nizina succession are found at the transition between these two formations. At this horizon in the Green Butte section several beds contain highly diverse,

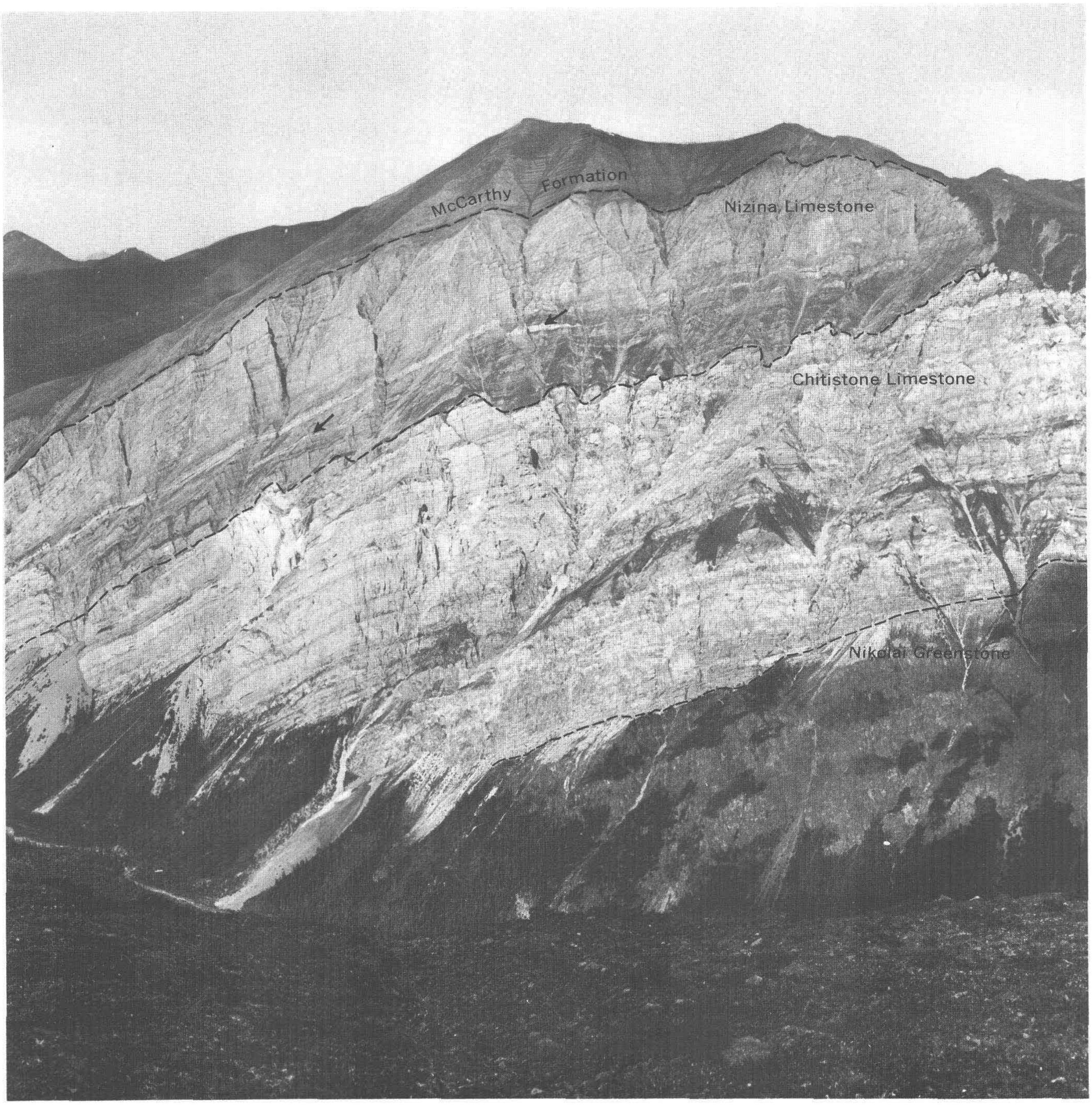


FIGURE 7.—The west face of Green Butte as viewed from the hills west of McCarthy Creek. The arrows point to light-gray limestone tongues which are believed to have been formed by submarine penecontemporaneous slides downslope from a carbonate shelf into the basinal micropelletoid grainstones in the lower part of the Nizina Limestone. Relief on the west face is 3,545 feet.

partly silicified concentrations of invertebrate megafossils that represent a latest Karnian or earliest Norian age (Silberling and Tozer, 1968, p. 48). Collections from this locality (USGS Mesozoic loc. M1708) include about 70 specifically distinct taxa of marine invertebrates, such as many different kinds of gastropods and pelecypods; several kinds of brachiopods; a variety of colonial corals and spongiomorphs; a few ammonites, nautiloids, and coleoids; crinoid columnals; echinoid spines; and calcareous worm tubes. These fossils occur as tightly packed aggregates of delicate shells, both broken and unbroken, mixed with many fragments of corals and spongiomorphs, which suggests that they accumulated more or less in

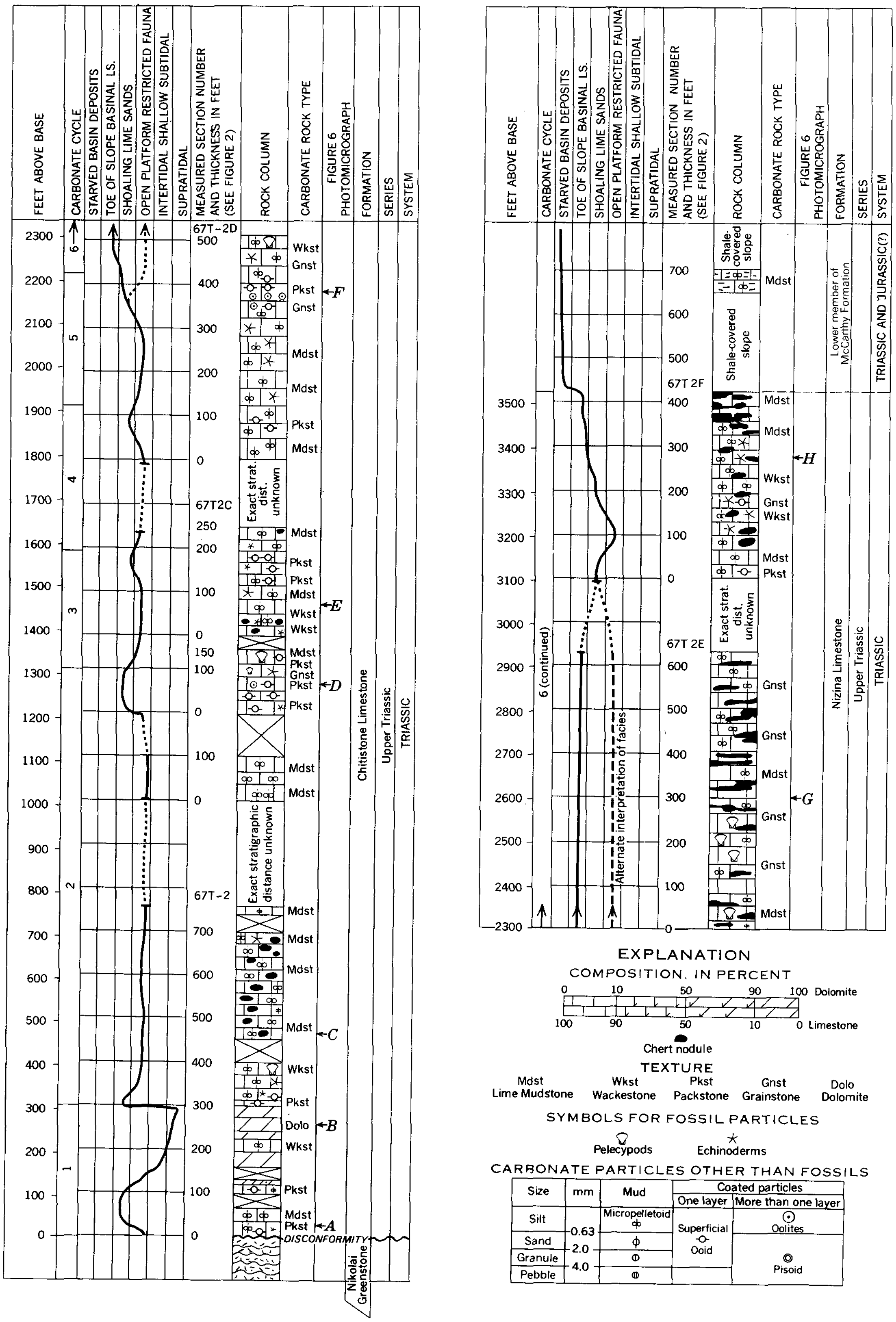


FIGURE 8.—Composite Upper Triassic stratigraphic section at Green Butte. Location of each of the stratigraphic segments is shown on figure 2. The environmental interpretation is shown to the left of the rock column, and the possible carbonate cycles are also listed. To the right of the rock column the stratigraphic positions of the photomicrographs shown on figure 6 are listed.

place and have not been extensively reworked or redeposited by submarine sliding. Similar, though taxonomically less diverse, occurrences have also been found elsewhere in the McCarthy quadrangle in the basal part of the Nizina Limestone.

At Green Butte this fauna occurs about 100 feet above the well-sorted oolitic beds which are near the top of the Chitistone Limestone. These beds are believed to be shoal lime sands deposited at the seaward edge of the carbonate platform. The fauna is found in the lower part of the slope basinal limestones and appears to represent the assemblage that flourished in the shallow waters just seaward from the lime sand shoals where the greatest abundance and diversity of marine life would be expected to occur (Purdy, 1963, p. 495, fig. 4).

In the higher parts of the Nizina Limestone, megafossils are not uncommon, though rarely are they well preserved. Brachiopods, gastropods, ammonites, and pelecypods were collected from a number of localities during the present study and in the course of the geologic mapping. Among the pelecypods, floating or attached-floating shells of *Halobia* are well represented, as are certain bottom-dwelling forms, especially those tentatively referred to as *Gryphaea*.

In the beds transitional from the Nizina into the overlying shales and cherts of the McCarthy Formation a few miles northeast of Green Butte (at USGS Mesozoic loc. M1695), a poorly preserved ammonite fauna includes the distinctive genus *Pterotoceras*—an early middle Norian age form. Thus the 3,500 feet of Upper Triassic carbonate rocks of the Chitistone and Nizina Limestones in this part of the Wrangell Mountains ranges in age from late Karnian through the early part of the Norian.

DEPOSITIONAL MODEL

The Chitistone and Nizina Limestones are lithologically and stratigraphically similar to many other carbonate sequences of various ages in other parts of the world. They are composed predominantly of lime mud and particles formed of lime mud. They record deposition on a broad slowly subsiding carbonate platform separated from an offshore submarine slope by a relatively narrow partial barrier of shoal lime sands. Although shelly marine life flourished on the seaward edge of the lime shoals and contributed much fine-grained calcareous detritus to the shoals and platform, organic reefs evidently were not developed at the platform edge. On the platform, shoreward of the shoals, the environment was evidently inhospitable to most kinds of marine invertebrate animals.

The Chitistone and Nizina Limestones have not yet been studied over a large enough area to determine the paleogeography of the carbonate shelf on which they were deposited, but some measure of its dimensions is suggested by the occurrence of correlative carbonate rocks to the east in nearby parts of the Yukon Territory, Canada. The 500 feet of limestone in the Mush Lake Group, which is exposed 100 to 140 miles east of the Kennecott district, is correlated by Muller (1967, p. 50, 54) with the Chitistone and Nizina Limestones and is described as being mostly massive, indistinctly bedded, yellowish- and reddish-weathering limestone including some gypsum and anhydrite. The occurrence of evaporites in these rocks suggests that they represent the far inshore part of the carbonate platform.

A modern analog of this Upper Triassic carbonate shelf, but possibly on a smaller scale, is the area of deposition of lime mud sediments in Florida Bay which extends some 150 miles east of the seaward western edge of the Florida Platform (Ball, 1967, p. 577–579). A similar, but somewhat poorer, model is the area of deposition of lime mud and soft pellet lime mud in the shallow waters on the west side of the Bahama Banks adjacent to Andros Island (Purdy, 1963, fig. 1). The bulk of the lime mudstone in these modern carbonate deposits may be formed of the clay-size (less than 15 micron) particles produced in the tissue of shallow-water green algae like *Penicillus* (Stockman and others, 1967).

A model of a long ramp platform illustrating the various depositional environments for the Chitistone and Nizina Limestones is shown on figure 9. The significant or diagnostic rock types found in each environment are also shown. The thickness of any one carbonate facies at any given geographic location depends upon the rate of subsidence and the rate of carbonate deposition. For example, the shoaling sand belt shown on figure 9 would move to the right or landward, with a rise of sea level, and to the left or seaward with a fall of sea level. Equilibrium between the rate of subsidence and the rate of carbonate production would result in a very thick section of shoaling-water carbonate sand. (For further discussion of these principles see Macqueen and Bamber, 1968, p. 266–269; Armstrong, 1967, p. 9–11; Wilson, 1967c; Ginsburg, 1966; Kinsman, 1966.)

CARBONATE ROCKS NEAR THE KENNECOTT MINES—POSSIBLE RELATION TO ORE DEPOSITION

The large copper deposits at the Kennecott mines are localized in the lowermost few hundred feet of the Chitistone Limestone—a localization that suggests a strong stratigraphic influence. Between 1908 and 1938,

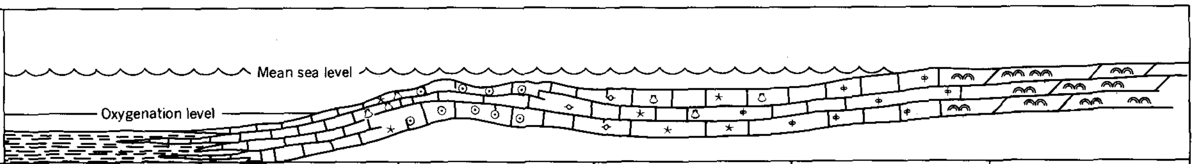
DIAGRAMMATIC CROSS SECTION						
FACIES	Starved-basin shales, radiolarian cherts	Toe-of-slope basinal limestones	Shoal lime sands	Open platform limited fauna	Shallow, restricted subtidal marine, tidal channels, intertidal	Supratidal, sebkhas, and ponds
LITHOLOGY	Dark-gray to black shales	Dark lime mudstone, micropelletoid grainstones	Light-colored limestones, fossil fragments, oolitic	Lime mudstones, clotted fossilferous wackestones, micropelletoid grainstones	Clotted lime mudstones, dolomitic, and dolomites	Stromatolitic, birdseye lime mudstones, dolomites
PHOTOMICROGRAPHS OF LITHOLOGY, FIGURE 6	None	*G*	*A,D,F*	*E,H,G*	*B,C*	(See figures 3,4)
BEDDING AND SEDIMENTARY STRUCTURES	Fissile shales	Fine laminae, microcut-and-fill structures, rare burrows	Small to massive crossbeds	Burrows	Burrows, birdseye structures, algal chips, stromatolites, tidal channel cut and fills	Birdseye structures, algal chips, stromatolites
SECONDARY INTERBEDDED TERRIGENOUS CLASTICS	Dark shale, silt-size quartz sand	Rare silt-size and smaller quartz sand	None	None	None	None
FORAMINIFERS	None to rare	Common	Common	Common	None	None
OSTRACODES	None	Rare	Rare	Common	Common	None
GASTROPODS	Rare	Rare to common	Common	Common	Rare	None
PELECYPODS	Rare to common	Common	Common	Common	Rare	None
AMMONITES	Rare to common	Rare to common	None	Rare	None	None
ECHINODERMS	None	Rare to common	Common	Common	Rare	None

FIGURE 9.—Depositional model for the Upper Triassic carbonate facies. (No horizontal scale intended.)

when the mines were operated on a large scale, they were among the world's leading copper producers and were noted for the size and tenor of their chalcocite-rich lodes.

The carbonate rocks of the lower parts of the Chitistone Limestone were investigated near the two largest Kennecott mines, the Bonanza and the Jumbo (fig. 1). The lowermost 70 feet of Chitistone Limestone at these mines consists of lime mudstone and an underlying 4-inch-thick layer of shaly limestone. Calcitic pellets are dominant in the mudstone and are between 10 and 20 microns in diameter. The lime mudstone here is petrographically similar to lime mudstones elsewhere near the base of the Chitistone Limestone. Similarities are found in the size and shape of the pellets and in the content of fragmented calcispheres, echinoderms, and mullusks. It differs from other Chitistone lime mudstones in containing abundant disseminated pyrite and a few scattered copper minerals.

The rocks between 70 and 350 feet above the base of the Chitistone Limestone near the Bonanza and Jumbo mines are markedly different from those studied elsewhere. They consist of dolomite composed of rhombs, from 100 to 200 microns long, and calcite pore fillings. The dolomite is massive and contains numerous lithoclasts and breccia zones that probably are of tectonic origin. Most of the ore was localized in the dolomite, although some extends downward into the lime mudstone. Most of the dolomite is believed to have been deposited from hydrothermal solutions moving through an extensive breccia zone. Consequently, the lithologic and sedimentary features of the rocks that originally occupied this zone have been either obliterated or replaced. Probably these rocks were originally intertidal and supratidal phases, similar to rocks in the lower part of the other Chitistone successions elsewhere. Conceivably both the ore deposition and the pyritization were related to the hydrothermal activity that produced the dolomitization.

Study of the depositional environment of the Chitistone Limestone and the distinctive properties of the host rock for the Kennecott ores could provide significant information about the genesis of the Kennecott deposits. An attractive speculation is that thermal brines played dominant roles in the ore formation. The importance of such brines as metal carriers has recently been emphasized by several geologists, notably White (1967, 1968) and Davidson (1965). Such brines are potent solvents of copper and many other metals, and they conceivably could also carry sulfur derived from supratidal evaporite deposits. Supratidal environments would be favorable sites for the generation of these brines. The brines could have been heated and mobilized during the major regional orogeny, near the close of the Jurassic or in the Early Cretaceous, or during the early stages of the extensive Tertiary vulcanism when Wrangell Lava was erupted and the plutons were emplaced. The thermal brines could have acquired their copper by migrating through parts of the copper-rich subjacent Nikolai Greenstone and subsequently rising to the brecciated dolomite, where conditions were favorable for ore deposition.

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PRELIMINARY REPORT ON THE PALEOZOIC AND MESOZOIC SEDIMENTARY SEQUENCE ON ST. LAWRENCE ISLAND, ALASKA

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Abstract.—Preliminary investigations in the eastern part of St. Lawrence Island indicate the presence of a heretofore unreported sedimentary sequence possibly as much as 8,000 feet thick. The oldest strata are a thick sequence of Devonian dolomite and dolomitic limestone exposed along the Seknak River. On the Ongoveyuk River these strata appear to be succeeded disconformably by at least 1,000 feet of Upper Mississipian limestone and cherty limestone which in turn are overlain disconformably by a 400-foot shaly sequence that is definitely of Middle and Late Triassic age in the upper part and probably of Early Triassic or Permian age in the lower part. The youngest sedimentary rocks appear to be a thick section of graywacke and mudstone along the Ongoveyuk River, tentatively assigned a Jurassic or Cretaceous age. The Paleozoic and Mesozoic sequence shows strong lithologic and faunal similarities to coeval rocks in the Brooks Range; and some counterparts appear also to be present on the Seward and Chukotsky Peninsulas.

During the summer of 1968, the U.S. Geological Survey began reconnaissance mapping, stratigraphic studies, and geochemical sampling of the bedrock areas on St. Lawrence Island in the northern Bering Sea. These investigations are part of a broad program of onshore and offshore studies pointed toward assessing the mineral resources of the Bering Sea shelf (fig. 1). St. Lawrence Island by virtue of its unique geographic position serves as a valuable "window" to the subbottom geology of the shelf and is vital to the interpretation of marine geophysical data.

The purpose of this paper is to report briefly on a heretofore little known sequence of Paleozoic and Mesozoic rocks exposed in the eastern part of St. Lawrence Island. These rocks are of regional significance because they provide a stratigraphic tie between mainland Alaska and eastern Siberia and, hopefully, shed some light on the puzzling tectonic relationships between the North American and Asian landmasses. In addition, they are important to the search for new sources of petroleum because they suggest that large parts of the Bering Sea shelf may be underlain by a thick section of Paleozoic carbonate rocks.

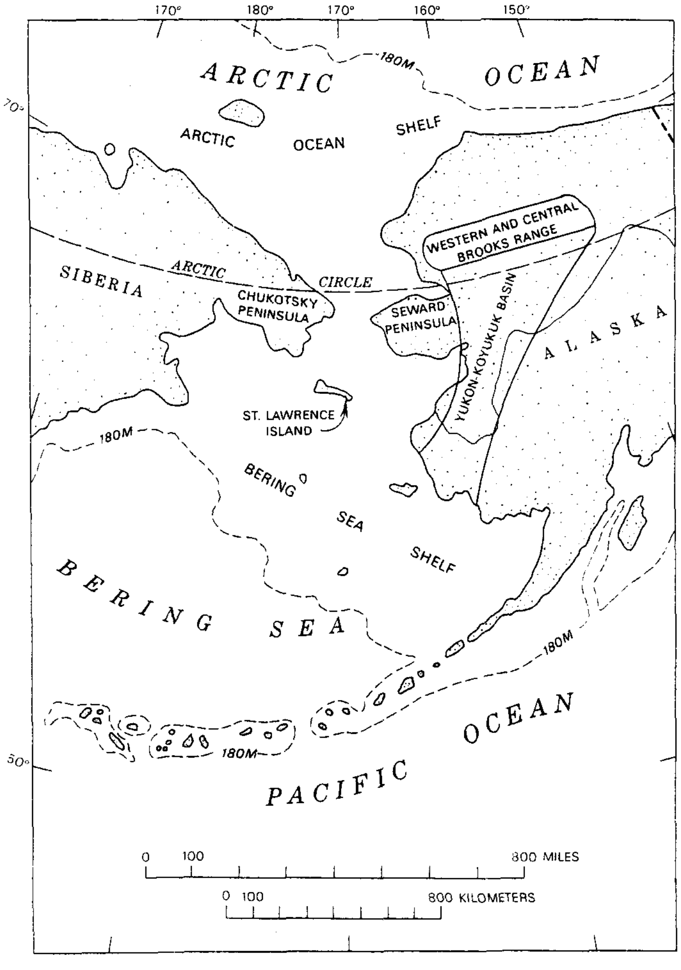

FIGURE 1.—Index map showing St. Lawrence Island and shelf areas of the Bering Sea and Arctic Ocean.

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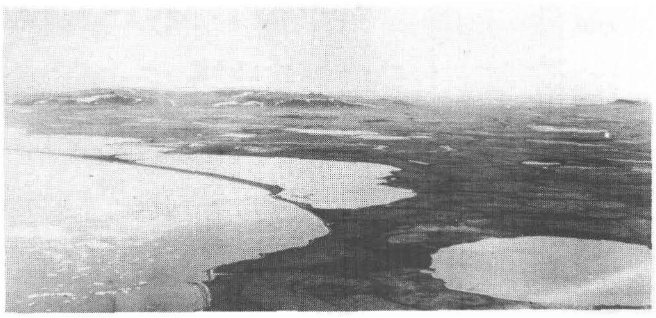
The stratigraphic data presented in this report are based on 3 weeks of fieldwork during July 1968. Inasmuch as only a small portion of the eastern part of the island has been critically examined thus far, these data should be regarded as preliminary and tentative.

Published information on the geology of St. Lawrence Island is confined to exploratory surveys along the coast (Dawson, 1894; Emerson, 1904, p. 38–42; Collier, 1906). Except for a brief mention of the Triassic strata by Martin (1926) and the information shown on the "Geologic Map of Alaska" (Dutro and Payne, 1957), no information has been published about the Paleozoic and Mesozoic sedimentary rocks.

GEOLOGIC SETTING

The eastern part of St. Lawrence Island is a broad, wave-cut bedrock platform now elevated a few feet to nearly 100 feet above sea level (fig. 2*A*). The surface of the platform is dotted with countless small shallow lakes and blanketed by a thin veneer of water-soaked mossy turf and peat. Several isolated groups of talus-covered hills, which are bounded by ancient sea cliffs and probably represent former islands, rise 1,000 to 2,000 feet above the surface of the platform.

The Paleozoic and Mesozoic strata are sparsely exposed along small drainages incised as much as 30 feet into the platform (fig. 2*B*). The best exposures of these rocks are found along the Ongoveyuk, Seknak, and Maknek Rivers and their tributaries (fig. 3). Even along these drainages, however, the exposures are discontinuous and the bedrock is largely reduced to frost-riven talus.



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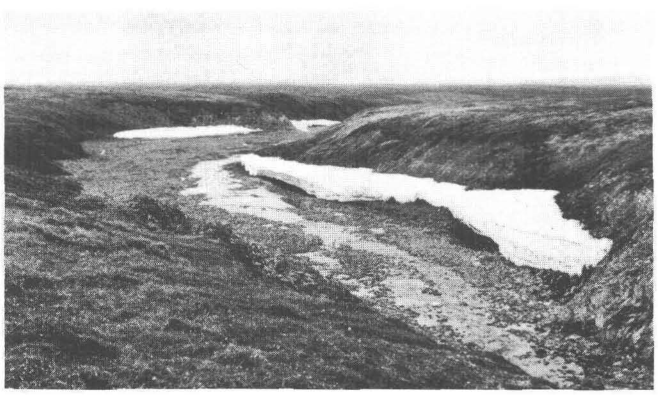


B

FIGURE 2.—Views of St. Lawrence Island, Alaska. *A*, Eastern part of St. Lawrence Island from north coast, showing wave-cut platform carved across folded Paleozoic and Mesozoic sediments. Hills in background composed chiefly of granitic intrusives. (Photograph by U.S. Navy.) *B*, Incised tributary of Ongoveyuk River with cutbank exposures of Mississippian and Triassic strata in foreground and middle distance and Jurassic-Cretaceous(?) strata in background. (Photograph by T. P. Miller.)

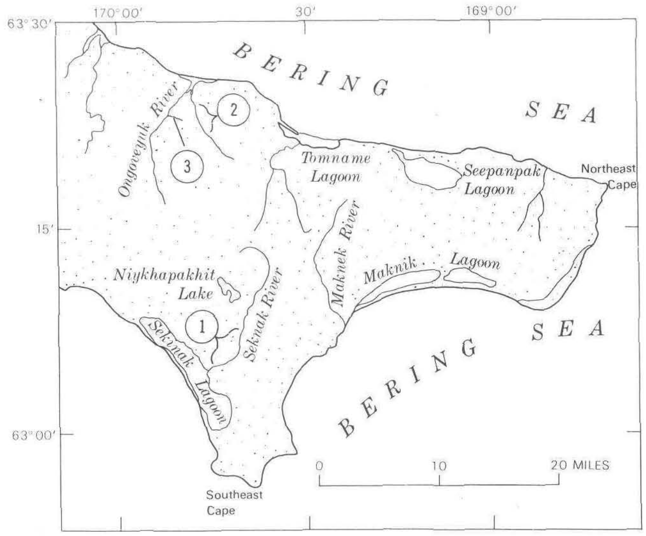


FIGURE 3.—Map of eastern St. Lawrence Island, showing location of Paleozoic and Mesozoic sections 1, 2, and 3 (see fig. 4).

Bedding attitudes where discernible indicate that the Paleozoic and Mesozoic strata are everywhere highly folded with dips locally as steep as 90°. The gross distribution of the rock units suggests that these strata have a north to northeast regional strike and a west to northwest regional dip. Examination of aerial photographs reveals that all the bedrock units are cut by two sets of lineaments trending approximately N. 50° E. and N. 25° W.

Granitic intrusives and volcanic rocks of late Mesozoic and Cenozoic age, which underlie all the hilly areas as well as large parts of the wave-cut platform, have thermally altered broad areas of the surrounding sedimentary rocks. In addition, all the sedimentary rock units are pervasively intruded by a variety of felsic and mafic sills and dikes.

DEVONIAN

The oldest rocks recognized in the eastern part of St. Lawrence Island comprise a thick sequence of dolomites and dolomitic limestones of probable Devonian age. These rocks are widely exposed along the Seknak and Maknek Rivers on the south side of the island and in a small area along the Ongoveyuk River on the north side of the island.

The bulk of the exposed sequence (fig. 4) is composed of medium-gray to brown, laminated, locally brecciated dolomite and dolomitic limestone which contain poorly preserved *Amphipora*(?). In the upper part these beds grade into dark-gray to black, fine-grained, thin-bedded dolomite with abundant *Amphipora*(?) and corals. A few thin beds of black chert and black silty dolomite are intercalated near the top of the sequence.

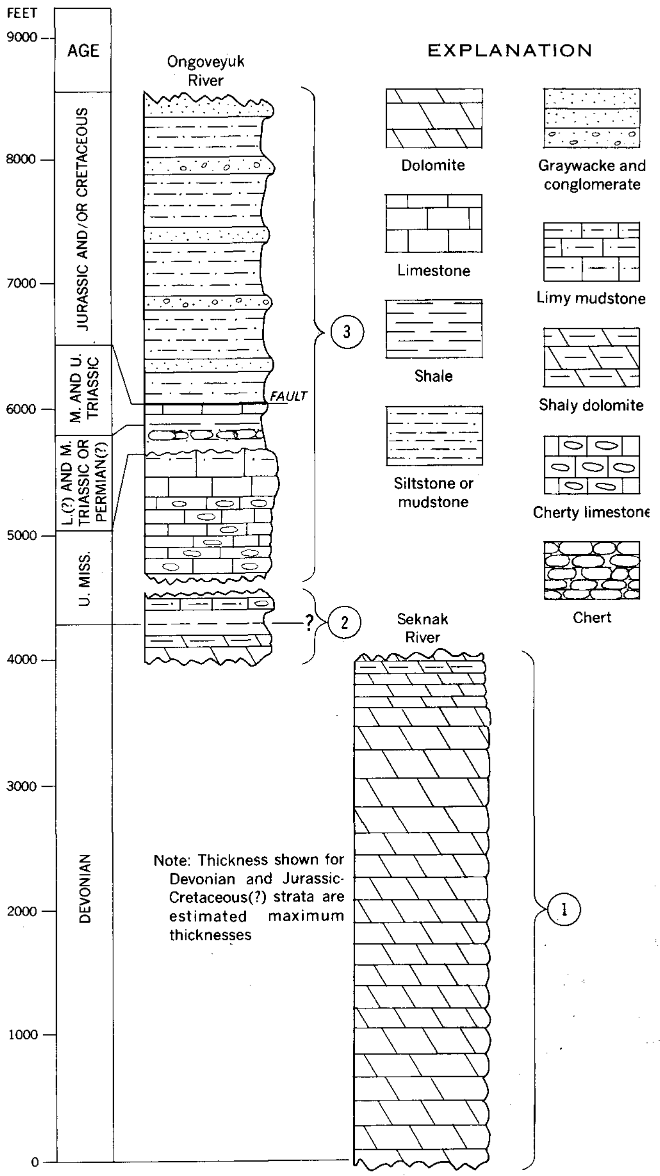


FIGURE 4. Generalized columnar section of Paleozoic and Mesozoic sedimentary rocks, eastern St. Lawrence Island (see fig. 3 for location of sections).

The sequence is best exposed along the lower Seknak River (fig. 3) in a series of discontinuous cutbanks. The beds strike uniformly north-northwest and dip on the average of 30° NE. Judging from the width of outcrop, the sequence may be as much as 4,000 feet thick. The top of the sequence is not exposed on the Seknak River. On the Ongoveyuk River, however, dark thin-bedded dolomites similar to those in the upper part of the Seknak River section are succeeded by cherty and sandy limestones of Late Mississippian age.

Five collections of stromatoporoids and corals from the Seknak River sequence were examined by W. A. Oliver, Jr. (written commun., 1968), who reports that they represent the stromatoporoid genus *Amphipora*(?) and tabulate corals including *Favosites* and thamnoporoid forms. He states that a Devonian age is strongly suggested, possibly Givetian or Frasnian, although these fossil groups range earlier into the Silurian.

MISSISSIPPIAN

Strata of Mississippian age are widely distributed along the Ongoveyuk River in the northern part of the island and occur in scattered rubble patches around the shores of Niykhapakhit Lake in the central part of the island. These rocks can be divided informally into two members (fig. 4): a thin-bedded dark cherty member below, and a thick-bedded light-colored limestone member above. The lower member, about 600 feet thick, contains abundant dark-gray chert nodules—as much as 35 to 40 percent in the upper 50 feet and 5 to 20 percent in the lower part. The upper member, about 350 feet thick, is nearly chert free and is composed chiefly of light- to medium-gray, medium to coarsely bioclastic limestone. Limy mudstone makes up about 30 percent of the top 50 feet of the member.

The total thickness of the Mississippian sequence in the Ongoveyuk River area probably does not exceed 1,500 feet. Nearly 1,000 feet of section, including the upper contact, is almost completely exposed on a small tributary of the Ongoveyuk River (fig. 3). The lower contact is not exposed at this locality, but on the east fork of the Ongoveyuk River, fossiliferous cherty and sandy limestones of Late Mississippian age are separated from dolomites of probable Devonian age by only a narrow covered interval (figs. 3 and 4).

Fossils of Late Mississippian age were found at several levels in the sequence. Among the more significant forms are the brachiopods of the genus *Gigantoproductus* that occur about 100 feet above the base of the upper member. This interval correlates broadly with the *Gigantoproductus* Zone in the upper part of the Alapah Limestone of the central Brooks Range sequence (Bowsher and Dutro, 1957, p. 5–6; Yochelson and Dutro, 1960, fig. 24).

Three collections near the base of the sequence contain many specimens of what is probably a new species of *Rugosochonetes*, together with a rich endothyroid microfauna of Viséan age, according to A. K. Armstrong (written commun., 1966). An assemblage from the lower 200 feet of the sequence (corals identified by W. J. Sando, written commun., 1968) includes:

Caninia sp.
Syringopora (*Kuiechowpora*) cf. *S. virginica* Butts
Zaphrentites sp. (large)
echinoderm debris, indet.
ramose bryozoans, indet.
Anthracospirifer sp.
productoid fragment, indet.

Sando states that the corals "* * * indicate a possible early Chester age, although a late Meramec age cannot be ruled out."

Another collection from an indeterminate level in the sequence contains *Ekvasophyllum*? sp. that suggests to Sando (written commun., 1968) either an early or middle Meramec age. A lithostrotionoid coral collected as float by T. P. Miller in 1966 was identified as *Lithostrotionella* aff. *L. mclareni* Sutherland by Armstrong (written commun., 1966), who suggested that it indicates a Meramec age. According to Armstrong, similar corals occur in the lower part of the Alapah Limestone in the central Brooks Range, together with Meramec age endothyroids and brachiopods.

Thus, the faunal evidence indicates that the sequence is approximately correlative with the Alapah Limestone, with an age range from early Meramec through possible early Chester. Foraminifera from eight of the collections made in 1968 were examined by Bernard Mamet, Université de Montréal, who states (written commun., March 31, 1969):

> The encountered microfauna is very poor. Widespread occurrence of the "*Brunsia*-facies" eliminates most of the foraminiferal markers * * *. All foraminiferal-bearing horizons have an age ranging from Early Late Visean to Early Late Late Visean; this correlates with the late Meramec-earliest Chester.

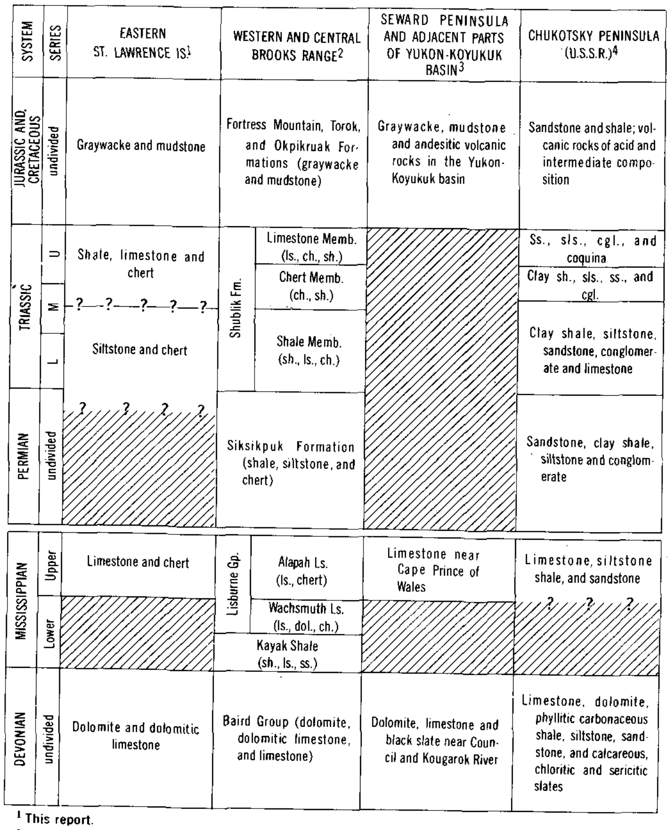
Collections from the lower 600 feet of the sequence contain foraminiferal assemblages assigned by Mamet to his Zones 14–15 (late Meramec). Two collections from the upper 300 feet of the sequence contain assemblages that may range as high as Mamet's Zone 16i (earliest Chester).

TRIASSIC

The Mississippian strata on the Ongoveyuk River are overlain by a 400-foot siltstone, shale, dark chert, and limestone section that contains Triassic fossils in the upper part. Similar rocks also were found at scattered localities along the streams that drain into Tomname Lagoon. Triassic fossils have been identified in float from the northwestern part of the island, but the presence of Triassic bedrock in this part of the island has not been established.

The upper 170 feet of the Ongoveyuk River section (fig. 4) is chiefly black shale and dark thin-bedded limestone and chert. Flat clams identified as *Daonella*, *Halobia*, and *Monotis* by N. J. Silberling (written commun., 1968) occur in vertical sequence and indicate a condensed section including beds of Ladinian, Karnian, and Norian age. The lithologic and faunal character of these beds is remarkably similar to that of the upper part of the Shublik Formaton (Limestone and Chert Members) in the Brooks Range of northern Alaska (Patton and Tailleur, 1964) (fig. 5).

The lower 225 feet of the Ongoveyuk River section is mostly thin-bedded chert and dark siltstone. These beds have yielded no fossils, but their lithologic character suggests a possible correlation with either the Shale Member (Early? and Middle Triassic) of the Shublik Formation or the Siksikpuk Formation (Permian) (fig. 5).



[1] This report.

[2] Patton and Tailleur (1964), Bowsher and Dutro (1957), and Tailleur, Brosgé, and Reiser (1967).

[3] Patton (1967), Steidtmann and Cathcart (1922), and Gryc, Dutro, Brosgé, Tailleur, and Churkin (1967).

[4] Sachs and Strelkov (1961), Markov and Tkachenko (1961), and Krasny (1964).

FIGURE 5. Suggested correlation of Paleozoic and Mesozoic sequences on eastern St. Lawrence Island, western Alaska, and Chukotsky Peninsula (U.S.S.R.).

JURASSIC-CRETACEOUS(?)

The youngest Mesozoic strata seem to be a thick sequence of graywacke and mudstone which is tentatively assigned a Jurassic or Cretaceous age. These rocks are extensively exposed along the middle course of the Ongoveyuk River and also occur in scattered patches of rubble along the streams that drain into Tomname Lagoon. As yet, however, they have not been identified elsewhere on the eastern part of the island.

Gross structural relationships clearly suggest that these graywacke and mudstone strata immediately overlie the Triassic beds, although the exposed contact on the Ongoveyuk River is complicated by faulting. The upper contact is not exposed, but it appears that these strata dip northwestward beneath the Cenozoic(?) volcanic rocks that crop out along the lower Ongoveyuk River.

No fossils have been found in the graywacke and mudstone beds, and their tentative age assignment is based on: (1) their apparent stratigraphic position above the Triassic strata and below the Cenozoic(?) volcanic rocks, and (2) the widespread occurrence of graywacke and mudstone of Jurassic and Cretaceous age in adjacent parts of mainland Alaska.

The graywacke, which makes up 15 to 25 percent of this unit, is typically a dark-greenish-gray, well-indurated, poorly sorted, fine-grained, muddy sandstone that locally displays sole markings, graded bedding, and other features characteristic of turbidites. Thin intraformational polymict granule-pebble conglomerate and shale-chip conglomerate are sparsely distributed through the unit. Both the graywacke and the mudstone are heavily sheared, in places so intensely that individual graywacke layers have been broken into disconnected, randomly oriented, slickensided blocks which are enveloped in a mudstone paste.

Accurate measurements of thickness of this unit are not possible because structure is locally complex and exposures are incomplete. The width of outcrop and the regional dip of the strata indicate that the unit may be as much as 2,500 feet thick.

CORRELATIONS

The Paleozoic and Mesozoic strata on eastern St. Lawrence Island show a marked resemblance to coeval rocks in the western and central Brooks Range, as indicated in figure 5. In addition, counterparts of some of the Paleozoic and Mesozoic strata appear to be present on the Seward and Chukotsky Peninsulas.

Devonian rocks are widely distributed in the Brooks Range and include a thick section of dolomite and limestone that bears a characteristic stromatoporoid and coral fauna (Tailleur and others, 1967). Similar carbonate rocks, of probable Devonian age, are reported on the Seward Peninsula, but few details of their stratigraphy are known. (Gryc and others, 1967.)

Upper Mississippian limestone and cherty limestone beds containing a coral and brachiopod fauna identical with that found on St. Lawrence Island are extensively exposed in the western and central Brooks Range (Bowsher and Dutro, 1957; Sable and Dutro, 1961). Coral-bearing limestone of probable Late Mississippian age has also been recognized in a small exposure near Cape Prince of Wales at the extreme western end of the Seward Peninsula (Steidtmann and Cathcart, 1922).

The Upper and Middle Triassic strata on St. Lawrence Island closely resemble the upper part of the Shublik Formation in the western Brooks Range, and the shaly beds underlying these fossiliferous strata may be correlative with the lower part (Lower? and Middle Triassic) of the Shublik Formation or with the Siksikpuk Formation (Permian). Triassic strata were thought to be present in the western Seward Peninsula, but recent investigations in this area by C. L. Sainsbury (oral commun., 1969) indicate that most, if not all, of the rocks previously mapped as Triassic (Dutro and Payne, 1957) are pre-Ordovician in age.

Graywacke and mudstone strata of Jurassic and Cretaceous age similar to those found on St. Lawrence Island are widely distributed in western and northern Alaska. Rocks of this character make up nearly all the Cretaceous strata of the Yukon-Koyukuk basin (Gates and others, 1968) and all the Jurassic and Early Cretaceous beds of the western and central Brooks Range.

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