Geology of the Eastern Part of the Mount Fairweather Quadrangle Glacier Bay, Alaska

By DARWIN L. ROSSMAN

CONTRIBUTIONS TO GENERAL GEOLOGY

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A study of an area of highly recrystallized rocks and complex structures related to the Coast Range batholith

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GEOLOGY OF THE EASTERN PART OF THE MOUNT FAIRWEATHER QUADRANGLE, GLACIER BAY, ALASKA

By Darwin L. Rossman

ABSTRACT

Rocks on the west side of Glacier Bay in southeastern Alaska are predominantly sedimentary, and consist chiefly of thin-bedded and massive limestones and some argillaceous rock. The five formations recognized, from oldest to youngest—the Willoughby limestone, Tidal formation, Pyramid Peak limestone, Rendu formation, and Black Cap limestone—have a total exposed thickness of about 26,000 feet, and range in age from Late Silurian to Middle Devonian. Several isolated sedimentary rock units, whose age and relative stratigraphic position are unknown, also crop out.

The most abundant igneous rock, diorite, underlies about one-third of the mapped area. This rock varies widely in composition and may include rocks of more than one age and mode of origin. Other igneous rocks include quartz diorite, granite, gabbro, and mafic and silicic dike rock.

Highly recrystallized stratified rocks, which are now banded amphibolite gneisses, lie in the southern part of the mapped area. A zone containing migmatite dikes also lies in the southern part of the mapped area. The zone is only a few hundred feet wide, but it extends at least 45 miles. The migmatite dikes show both intrusive and replacement relations to the host rock. Tactite, containing well-developed crystals, lies near a diorite contact in the northern part of the area.

Glacial advances occurred in the Glacier Bay area 7,000, 4,000, and 500 years ago. During the last advance, which was the most extensive, ice reached as far south as the entrance to Glacier Bay.

Only a few mineral deposits have been found. A small but rich silver deposit (now mined out) lay near the west shore of Rendu Inlet, and a molybdenite-bearing zone exists on the east shore of Muir Inlet. Some placer gold has been found at the foot of Brady Glacier and in the upper part of Dundas River. A few gold-bearing veins crop out betwen Dundas Bay and Brady Glacier and on the south shore of Gilbert Island.

Some sulfide minerals are present in massive limestone on Willoughby, Francis, and North Marble Islands. Hydrothermally altered rock is abundant along numerous fault zones in the northern part of the mapped area. Most of the alteration zones contain no quartz or minerals of economic importance, but the few that do contain quartz also contain some free gold. Paligorskite crops out in and on massive limestone on Lemesurier Island.

INTRODUCTION

LOCATION

The Glacier Bay area is in the northern part of southeastern Alaska, about 15 miles south of the international boundary between Canada and the United States, and midway between Lynn Canal and the Pacific Ocean. (See fig. 1.) It lies within the boundaries of the Glacier Bay National Monument, which is one of the outstanding scenic areas on the North American Continent. The mapped area includes about 1,000 square miles, almost half of which is covered by water or glaciers.

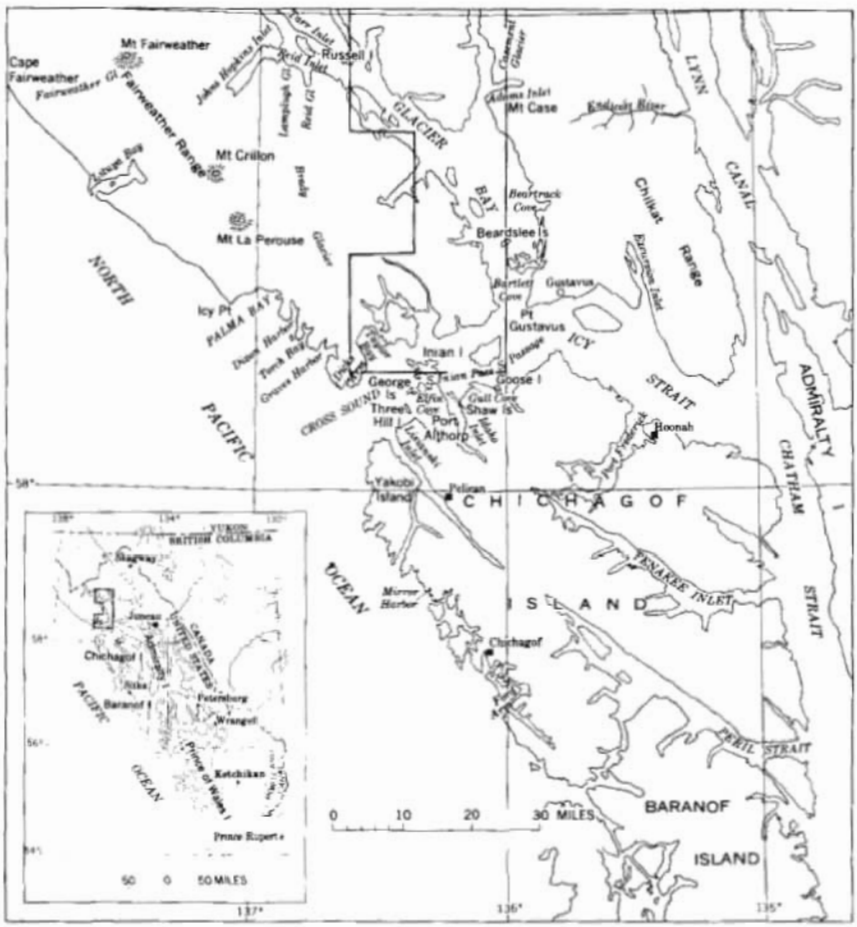

FIGURE 1.—Index map of southeastern Alaska showing location of the area mapped.

HISTORY AND PREVIOUS GEOLOGIC INVESTIGATIONS

Tlingit Indians were the earliest known inhabitants of southeastern Alaska (Brooks, 1953), and some traces of early Indian occupancy can still be found in the Glacier Bay area. The remains of an Indian settlement lie on a gravel plain west of Point Carolus, and traces of early Indian dwellings are still discernible along the shores of Dundas River a short distance above its mouth. Apparently a trail connected these two villages, but today only parts of it remain. Another village site lies on the shores of Willoughby Cove on the south side of Lemesurier Island, and Joseph Ibach, who lives there, reports that colored pictures could still be seen on a limestone cliff on the east side of the cove in the earlier part of the century.

On the upper slopes of the mountains throughout the southern part of the mapped area, as well as on Chichagof Island, are many rock cairns which the writer believes were built in prehistoric time. These rock cairns are found at almost any place on the upper slopes of the mountains, but generally are in the vicinity of some prominent point, such as a peak or a mountain shoulder. They are also in less conspicuous places and may be found in saddles and cirque basins. Commonly several stand within a distance of a few hundred or tens of feet of one another. They do not appear to be placed in any regular geometric pattern, and it does not seem possible that they could have been used as places of concealment in hunting or war. Their random distribution and their number preclude the possibility that they are either claim corners or cairns used as survey stations, although both of these types of cairns are common in the same area.

These ancient cairns range in size from piles of rocks 2 feet in diameter and 1 foot high to cairns 8 feet long and 5 feet high. The best preserved one stands on a 1,700-foot hill on the east side of Inian Peninsula 1⅛ miles east of the head of Port Althorp. This cairn has the shape of half an ellipsoid. The rocks in it were all obviously collected in the immediate vicinity and have been fitted together with considerable care and skill.

Much of Alaska, particularly the coastal region, was visited by Russian explorers and fur traders in the late 1700's and early 1800's (Brooks, 1953), but there are no records known to the writer in which the Russians specifically mentioned Glacier Bay, although they probably visited the area. A brass compass marked with Russian characters was found in the vicinity of a small lake about 2 miles east of Dundas Bay, and a stock from an ancient musket was found by Joseph Ibach some time before 1936 on the upper reaches of Lamplugh Glacier about 7 miles from tidewater. Recently the remains of an early cabin, which may have been of Russian origin,

were discovered at Willoughby Cove on the south shore of Lemesurier Island.

One of the first records mentioning the Glacier Bay area was made by Vancouver. In 1794 some of his men, under the direction of Widbey, sailed past the entrance of Glacier Bay while exploring and mapping the west coast of America in search of the northwest passage (Vancouver, 1801).

Although many people must have visited and seen Glacier Bay between 1794 and 1879, very little was published concerning it until Muir published the account of his trip in 1879 (Muir, 1895). He visited the area in 1879, 1880, and 1890. His activities consisted mainly of mapping the position of the ice fronts and making several trips across the glacial ice.

Some prospecting was done in the area at an early date. Two silver claims were located on the east shore of Rendu Inlet in about 1892 (p. K48). Sulfide minerals were found on Observation Mountain, on Francis and Drake Islands, and on Willoughby Island before 1915. Mr. Mike Marvitz, one of the early residents, discovered gold on some of the gravel-covered icebergs coming from Lamplugh and Johns Hopkins Glaciers some time before 1924, and Mr. Ibach, of Lemesurier Island, discovered a gold-bearing area between Reid Inlet and Lamplugh Glacier in 1924.

The Glacier Bay area was closed to prospecting in 1924 pending determination of the area that should be set aside as a national monument; on February 26, 1925, the upper part of the Glacier Bay area was made into a national monument. Glacier Bay National Monument was enlarged in 1939 to include all Glacier Bay and all the land between Glacier Bay and the Pacific Ocean.

One of the first geological studies of the area was made by G. Frederick Wright (1889), who went to the Glacier Bay area in 1866 to study Muir Glacier. In the spring of 1890 a party consisting of H. F. Reid, H. McBride, J. F. Morse, C. A. Adams, R. L. Casement, and H. P. Cushing visited Glacier Bay to explore and map the basin of Muir Glacier. A brief report on this visit was published by Cushing (1891). Reid, who visited the area in both 1890 and 1892, prepared a geologic map of the Glacier Bay area, as well as several topographic maps on which he showed the position of the glacial fronts (1896).

C. W. Wright and F. E. Wright, of the U.S. Geological Survey, spent 2 months in 1906 mapping some of the geology and investigating the glaciers of the area, but the work was left unfinished. J. B. Mertie, Jr., spent several weeks in the central part of the Glacier Bay area in 1919, and in 1931 C. W. Wright spent 3 weeks in the area; no

reports however, were published on either of these visits. J. C. Reed examined most of the known mineral prospects in the area in 1936 and published a short account of them (Reed, 1938). Reed and G. O. Gates visited the area again in 1940, but their visit was brief and the resulting report contains only a few detailed descriptions of prospects and an account of the mining activities in the area (Twenhofel and others, 1949).

These few investigations constituted virtually all that was known concerning the geology of the Glacier Bay area before the present investigation was undertaken in 1949.

PRESENT INVESTIGATION

The area discussed in this report was mapped as part of a long-range program of investigation of the geology in a broad belt across the northern end of southeastern Alaska. The mapped area includes five 15-minute quadrangles of the Mount Fairweather 1:250,000 quadrangle (fig. 1). These 15-minute quadrangles are Mount Fairweather B–1, B–2, C–1, D–1, and D–2. In this report the 15-minute quadrangles will be indicated by their letter-number designation, without the qualifying prefix of the name, Mount Fairweather quadrangle.

Fieldwork was begun in 1949, when the writer, assisted by James F. Seitz, geologist, and Salem S. Rice, geologic field assistant, spent July and August making a brief reconnaissance of most of the Glacier Bay and adjacent areas.

During 1951 mapping of the B–1, B–2, C–1, and D–2 quadrangles was completed.

In 1954 the writer with Charles Ratté, geologic field assistant, spent 24 man-days mapping the D–1 quadrangle. About 1 week was spent in the area in 1955. Altogether about 85 man-days have been spent on geologic mapping in these five 15-minute quadrangles. The B–1, B–2, and C–1 quadrangles were done by rapid reconnaissance, and the D–1 and D–2 quadrangles were mapped in some detail (pls. 1,2).

ACKNOWLEDGMENTS

During the course of the work many people cooperated in furthering the mapping program. Mr. Joseph Ibach, of Lemesurier Island, gave lodging to the party on several occasions and once made a special trip to the upper part of Glacier Bay to show the writer the location of some mineralized areas. He also supplied the party with fresh food on many occasions. Mr. Clell Hodson, of Elfin Cove and Pelican, transported the Survey party to Glacier Bay for a period of nearly 1 week.

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The National Park Service has consistently offered their cooperation in every way possible, and in 1955 they transported some of the Survey's field equipment from Glacier Bay to Juneau. Also during 1955 Dr. D. B. Lawrence, of the University of Minnesota, carried the Survey party and its camping equipment from Juneau to Glacier Bay. To all these people and organizations and to the many residents of Hoonah, Gustavus, Elfin Cove, Pelican, and Juneau who have helped the work in many ways, the writer wishes to express his gratitude.

GEOGRAPHY

The Glacier Bay area is mountainous and contains many large and active glaciers. It is cut by several major waterways, of which Glacier Bay is the largest; together with the adjoining inlets Glacier Bay is over 65 miles long and, at the maximum, about 14 miles wide. The bay extends northwestward from the southeast side of the Mount Fairweather quadrangle to a point beyond its north edge. Nine major inlets ranging in length from 5 to 25 miles join the bay. Of these, Muir, Tidal, Queen, Rendu, and Hugh Miller Inlets lie largely within the area discussed in this report. The southern part of the mapped area is covered in part by the waters of Icy Strait and Dundas and Taylor Bays.

Most of the streams are small. The largest, Dundas River, is about 12 miles long and drains an area of about 100 square miles. The river flows southward from the south end of Geikie Glacier through a wide low valley into Dundas Bay.

The mountains near the south edge of the area rise to a general altitude of about 3,000 feet. They become higher and more rugged to the north until at about the latitude of Geikie Inlet the highest mountains are about 5,000 feet in altitude. The mountains become still higher outside the mapped area to the northwest, culminating in the Fairweather Range, which has a maximum altitude of 15,300 feet. This range, although comparatively small in area, is one of the most rugged coastal mountain regions in North America. Cliffs and sheer mountain faces thousands of feet high are commonplace.

Many large glaciers lie within Glacier Bay National Monument; but all the large glaciers, except small parts of Brady, Casement, and Carrol, lie outside the mapped area. The northern parts of the D–1 and D–2 quadrangles (pl. 2) contain many small glaciers, most of which are the remnants of an ice sheet that covered much of the Glacier Bay area within the last few hundred years.

The retreat of the ice was followed closely by the vegetation that today reflects the amount of time passed since the retreat of the glacier. Trees, mainly spruce and hemlock as much as 2 feet in diameter, have

reforested favorable land as far north as Bear Track Cove. These forests are not yet mature, and, although dense, they are in general largely free of underbrush and windfalls. Farther north where large trees have not had time to grow, the vegetation is composed of bushy spruce, alder, devilsclub, ferns, grasses, and various berry bushes and broad-leaf plants. These are intergrown to form a dense, almost impenetrable, mat of vegetation. This brushy type of vegetation becomes sparse towards the north and nearly disappears beyond the latitude of Wachusett Inlet.

Glacier Bay National Monument is closed to all hunting and trapping, and many animals can be seen in their natural environment. Black bears are plentiful as far north as the latitude of Adams Inlet, and glacier bears which seem to be a subspecies of the black bear are also found in this same area. The large brown bears, related to the Kodiak bear, are few in number. Although none were seen on the west side of Glacier Bay, a few have been reported by prospectors. Tracks of several were seen in the area north of Tidal Inlet in 1954 and 1955. Wolves and coyotes range widely throughout the Glacier Bay area, and in recent years they have increased in number to the point where they have seriously depleted and in places exterminated the mountain goat herds. Today entire mountains can be traversed without finding any fresh signs of goats, although relict trails and gathering grounds indicate that within the last 10 years extensive herds lived in these areas.

Several herds of hair or harbor seals totaling several thousand animals live in the bays. Most of them live on the floating ice just in front of the more active glaciers. Otters have been seen at widely scattered places throughout the Glacier Bay area, and undoubtedly frequent all its waterways.

Glacier Bay has a wealth of bird life that is too varied to enumerate in this report. It includes most of the birds found along the Pacific coast of North America. One of the most plentiful birds is the scoter or old squaw duck, which can be seen in flocks of several thousand at almost any time during the summer months. Other birds include Canadian geese, cormorants, eider ducks, clam catchers, and sea parrots. Wood ducks live east of Berg Bay. Within the last several years the puffin, or sea parrot, has become plentiful, and in 1955 a flock estimated to contain nearly a thousand birds was seen at the entrance to Tidal Inlet.

The waters of Glacier Bay contain most of the common varieties of sea life including salmon, halibut, whales, and killer whales. Shrimp are locally abundant. The Dungeness crab is commercially fished at Bartlett Cove and Dundas Bay. King crabs are probably abundant

in the upper part of the bay, to judge from the numerous remains of the dead crabs found along the beaches. Salmon are gradually using more of the streams that are forming with the retreat of the ice. The farthest north that salmon have been observed is in a stream that enters the west side of the bay about 3 miles south of Reid Inlet.

At its maximum extent, Glacier Bay National Monument had within its borders a few residents who had established their homes there before the founding of the monument. A few people, probably five or six families, live on ranches near Gustavus, and one person lives on the east side of Dundas Bay.

The Civil Aeronautics Authority operates an air station at Gustavus, and the U.S. Coast Guard has a lighthouse at Cape Spencer. The National Park Service maintains a small house at Bartlett Cove for the use of the park ranger. These few houses and settlements constitute the only inhabited dwellings in the area. Several cabins and one mine mill have been built by miners and prospectors in the gold-bearing area between Reid Inlet and Lamplugh Glacier; a small cabin, probably a fisherman's cache, stands on the east side of Garforth Island. Commercial fishing is being actively carried on along the west coast and to a lesser extent in the Glacier Bay area itself. From time to time various interested persons are doing some prospecting and mining.

The climate in Glacier Bay is similar to that found throughout southeastern Alaska. In general it is mild and humid, but it varies from place to place because of local controls by the steep-sided valleys and fiords as well as the glaciers. No detailed weather records have been kept within the Glacier Bay National Monument except at Cape Spencer and at Gustavus. In general the upper part of the bay during the summer has more clear and partly clear days than does the area farther south. The air is generally several degrees colder within the monument, owing to the cooling brought about by the contact of the air with the ice and glacial melt water. The summer months from May through August are generally the driest, and the fall months from September through November are the wettest.

The waterways afford access to most of the mapped area. The entrance to Glacier Bay is about 90 miles from Juneau by water that is easily navigable by steamers and small boats. In general the waterways of Glacier Bay are deep and free of shoals and rocks. The bay has not yet been completely charted, however, and anyone entering it must proceed with caution. A tidal current as high as 6 knots sets through Sitkaday Narrows as the tide ebbs and flows. The ebb tide is generally the stronger because large volumes of glacial melt water are being added continuously to the bay and make the amount of

water leaving the bay greater than that entering it. Excessively high winds or waves are rare and during the time the work on this investigation was in progress, no severe navigational difficulties were caused by storms. During the summer months, however, the ice water on contact with the air gives rise to low-lying fog banks, which on many days completely cover the bay.

Icebergs periodically choke some of the inlets and bays and make navigation difficult or impossible. Characteristically the upper part of Muir, Wachusett, Tarr, and Johns Hopkins Inlets are too covered with ice to permit safe navigation. In the last several years, little glacial ice has been seen in the main arm of Glacier Bay south of Rendu Inlet, but previously this waterway was frequently choked with ice.

No modern trails or roads exist within the mapped area.

GEOLOGY

A thick succession of sedimentary rocks of Paleozoic age is exposed in the Glacier Bay area (pl. 1). A generalized columnar section is shown in figure 2. The oldest known rock is the massive Willoughby limestone of Silurian age, which is overlain by the Tidal formation. The rocks of the Tidal formation, which are predominantly thin bedded and argillaceous, are unconformably (?) overlain by the Pyramid Peak limestone which is composed of thin-bedded to moderately thick-bedded limestone. The Pyramid Peak limestone is conformably overlain by a thin-bedded sequence of interbedded limestones and argillites, the Rendu formation possibly of Late Silurian age; the upper surface of the Rendu formation probably is an angular unconformity. Overlying the Rendu formation is a succession of limestone beds of Middle Devonian age. The formations listed constitute all the sedimentary rocks exposed within the central part of the Glacier Bay area. Volcanic and sedimentary rocks believed to be of Mesozoic age crop out west of Dundas Bay. These rocks are correlative with others on Chichagof Island and near Lituya Bay that form a northwestward-trending belt along the west coast of southeastern Alaska. A similar parallel belt of rocks lies along the eastern part of southeastern Alaska. The rocks of both Paleozoic and Mesozoic age have been intruded, probably in Early Cretaceous time and later, by dioritic rocks. These rocks crop out in northwestward-trending belts and the igneous rocks in the western and northern parts of the mapped area are small parts of these intrusive rock bodies. The igneous rocks have extensively recrystallized the rocks with which they are in contact to amphibolites, high-grade schists, gneisses, and locally to tactites.

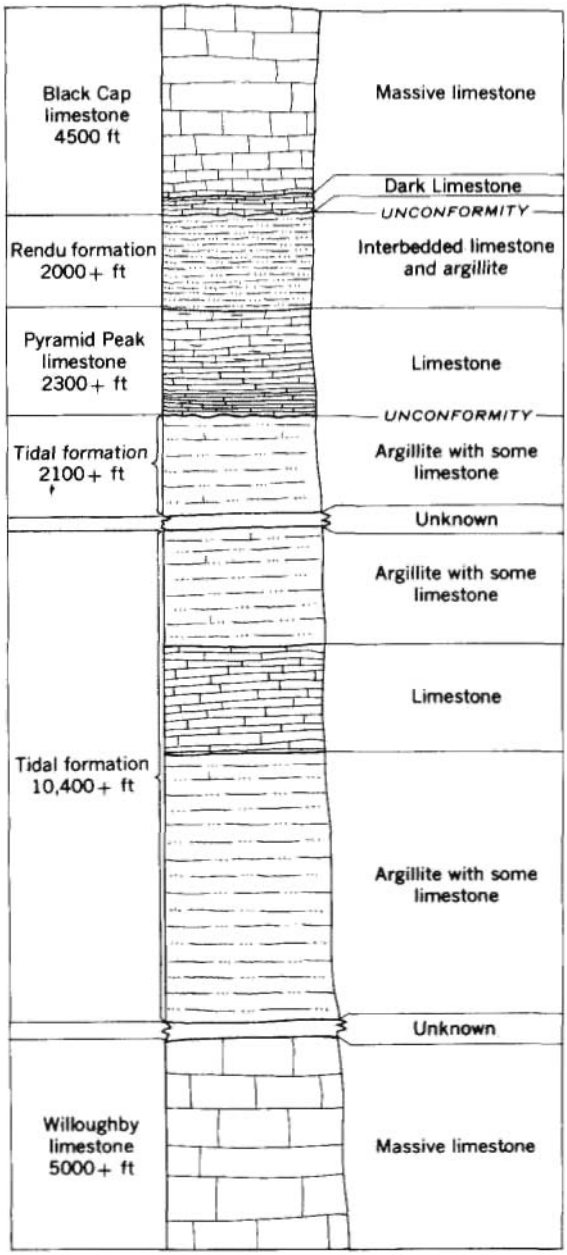

FIGURE 2.—Generalized columnar section of Paleozoic formations in the Glacier Bay area, Alaska.

SEDIMENTARY ROCKS

WILLOUGHBY LIMESTONE

The Willoughby limestone is here named to designate a succession of limestone strata of Late Silurian age. One of the best and most typical sections is exposed on Willoughby Island, from which the formation is named.

The southermost known exposure of the Willoughby limestone is on Lemesurier Island. The formation also crops out in a relatively narrow band, which extends northwestward from the north shore of Icy Strait opposite Lemesurier Island, and connects with the large flat-lying body of the Willoughby limestone that caps White Cap Mountain. North of White Cap Mountain the formation is intensely deformed, and crops out in small isolated and structurally complex units.

The Willoughby limestone also underlies the central part of the Glacier Bay area at about the latitude of Drake and Willoughby Islands. The northernmost mass crops out as far north as Tidal Inlet. All the above-mentioned outcrops have been assigned to the Willoughby limestone on both lithologic and fossil evidence, except for those on Lemesurier Island, White Cap Mountain, and north of White Cap Mountain. The belief that these latter rocks are part of the Willoughby limestone is based solely on their lithologic similarity to the rocks of the Willoughby limestone on Willoughby Island.

Cushing (1892) believed that this same formation crops out south of Sandy Cove, which is just southeast of the southeast corner of the D–1 quadrangle. The limestone at Sandy Cove however, seems to be in the stratigraphic position of the Pyramid Peak limestone, and is yellower than typical Willoughby limestone. The Pyramid Peak limestone is lithologically similar to the Willoughby limestone and may be mistaken for it, particularly where the rock has been recrystallized.

The Willoughby limestone is a massive blue-gray to white limestone. Bedding is characteristically difficult to see and is generally defined by slight differences in color rather than by variations in grain size. Where metamorphosed, the rock commonly loses all traces of bedding. Beds range in thickness from 2 inches to several tens of feet; normally, however, they are between 6 inches and 3 feet thick. Internal structures such as crossbedding are lacking. Small masses of blebs of sphalerite, galena, or pyrite, which range from a fraction of an inch to several tens of feet in diameter, are widely scattered through the Willoughly limestone. Commonly these blebs are near dikes, and may be related to them; some sulfide masses, however, seem to have been included in the limestone at an early stage of its formation.

Neither the top nor the bottom of the Willoughby limestone has been recognized; consequently, the nature of the rock with which it is in contact is unknown. The thickest known section crops out in Marble Mountain where the entire mountain, 3,366 feet high, is composed of the Willoughby limestone. Calculations based on the known structure of the limestone and the topography of the mountain indicate that the exposed thickness of the Willoughby limestone there is more than 5,000 feet.

The Willoughby limestone is fossiliferous, and although fossils are for the most part difficult to find, in certain areas—such as the northeast shores of both Drake and Willoughby Islands—the limestone contains large numbers of fairly well preserved marine invertebrate fossils. Generally they are calcareous and so firmly cemented in the limestone that they are difficult to remove intact. The most distinctive fossil is *Pycinodesma*, a giant mollusk that has been described by Kirk. (The type locality for this fossil is Willoughby Island.) *Pycinodesma* is easily recognized by its extremely thick shell which may be more than 1 inch thick.

Kirk considers that the fauna in the Willoughby limestone is of Late Silurian age (Kirk, 1927).

TIDAL FORMATION

A widespread argillaceous unit is here named the Tidal formation from the exposures along the shores of Tidal Inlet, which is in the lower central parts of the D–1 and D–2 quadrangles. A typical section is on the southwest flank of the 3,594-foot peak 2.8 miles southeast of the eastern end of Tidal Inlet.

The Tidal formation is fairly widely distributed in the southern part of the D–1 quadrangle and is exposed in a few small areas in the southeast corner of the D–2 quadrangle. Most of the southern flanks of Pyramid Peak and of the unnamed peaks east and west of Pyramid Peak are composed of the Tidal formation. Except for two dioritic stocks, all the peninsula south of Tidal Inlet consists of rocks of the Tidal formation, as do Mount Wright and the adjacent mountains to the east and southeast. The western flank of the mountain south of Mount Wright is also probably composed of rocks of the Tidal formation.

The Tidal formation consists predominantly of well-indurated fine-grained argillite. Outcrops are dominantly brown or gray, but the color of fresh rock ranges from black to nearly white. Several phases of the rock are shown in figures 3 and 4. The rock commonly shows extremely fine internal structural detail, such as lamellae scarcely thicker than a sheet of paper and very finely detailed crossbedding.

Although much of the material in this succession consists of clay- to silt-size particles, beds of sandstone and fine gravel are scattered throughout the section; in a few places all the beds in the succession for a few tens of feet are medium- to coarse-grained sandstones.

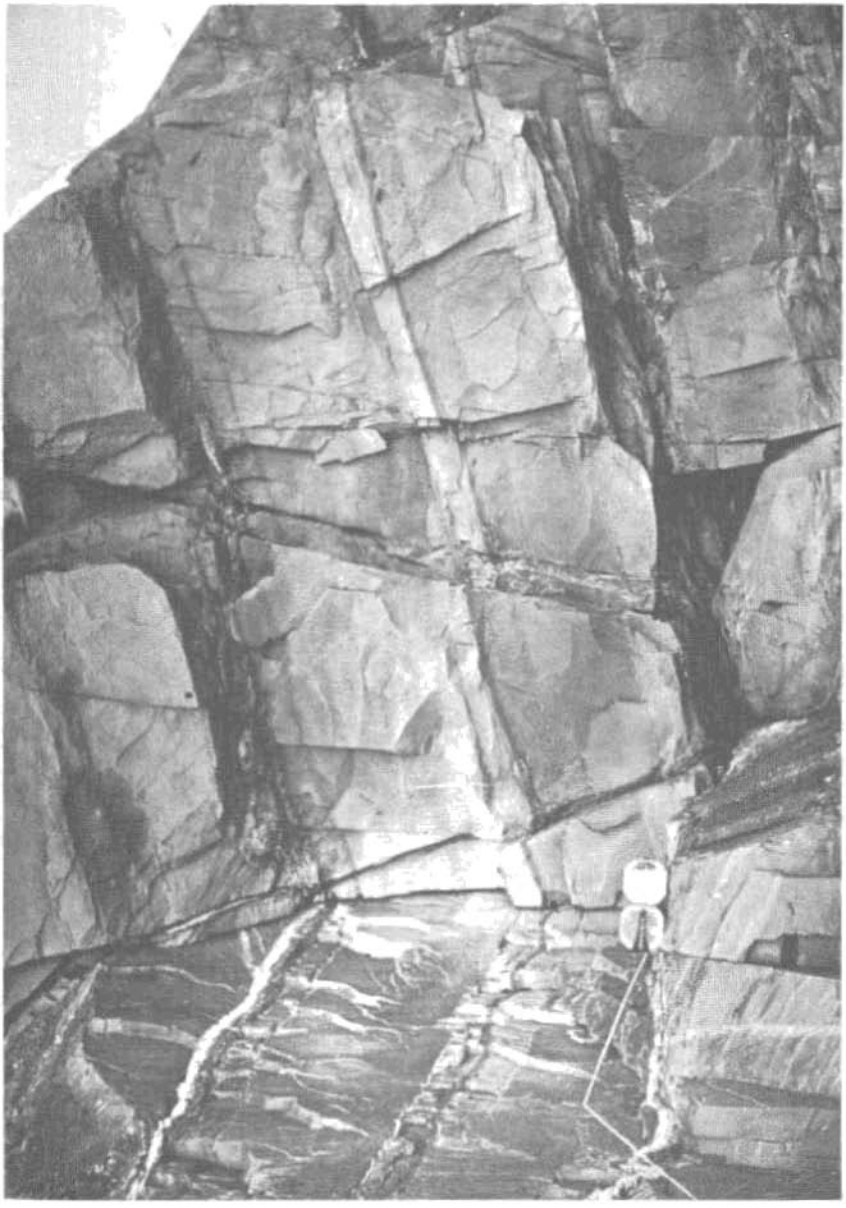

FIGURE 3.—Characteristic rock types of the Tidal formation. A sandy siltstone containing a large proportion of argillaceous material.

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FIGURE 4.—A characteristic rock type of the Tidal formation. A typical limestone outcrop of the thin-bedded limestone member.

Much of the formation is in some degree calcareous; calcareous beds range from slightly calcareous argillite to thin-bedded limestone, but generally are either calcareous argillite or argillaceous limestone.

However, one member 500 to 2,300 feet thick is composed of thin-bedded light-gray limestone. This member crops out in the top of several peaks south of Tidal Inlet and in an eastward-trending band on the main northern ridge of Mount Wright. The same limestone member can be traced by eye for several miles east of Mount Wright.

The relation of the Tidal formation to older rocks is not known because at no place within the mapped area has the lower contact been found. The contact between the Tidal formation and the overlying Pyramid Peak limestone is exposed on the west side of Pyramid Peak, on the east, south, and west sides of the unnamed peak west of Pyramid Peak, and 3 miles southeast of the head of Tidal Inlet. At most places the contact seems to be conformable, but on the south side of Pyramid Peak and southeast of the head of Tidal Inlet there is a suggestion of a slight angular unconformity.

The thickness of the exposed part of the Tidal formation can be estimated from the structure and topographic position of the various exposed segments of the formation. The thickest continuous section observed, which lies below the thin-bedded limestone member, is 5,500 feet thick; the thin-bedded limestone exposed on Mount Wright is 2,300 feet thick; and an incomplete section overlying the thin-bedded limestone is 2,300 feet thick. The total exposed section is believed to have a minimum thickness of 10,100 feet; but until additional evidence becomes available, the total thickness of the formation cannot be determined.

The Tidal formation is largely unfossiliferous, and little information is available concerning its age. A few calcareous fossils were found in the rock at an altitude of 4,400 feet at the base of the final peak on Mount Wright. Here the fossils, all small, were found as molds. The lot was examined by A. J. Boucot, who concluded that the fossils were not sufficiently diagnostic to be assigned an age closer than Silurian or Devonian.

Other fossil-bearing rocks were found near the shoreline of Glacier Bay, 2 miles north of Sandy Cove. Unfortunately the rocks at this locality are not completely typical of those of most of the Tidal formation; and because of the considerable structural complexity in the area, they have not been proved conclusively to belong to the Tidal formation. The rocks are found a few hundred feet below a well-bedded limestone that may be part of the Pyramid Peak limestone; if this correlation is correct, then the rock is part of the Tidal formation. Boucot examined the invertebrate fossils collected from this locality, but found nothing to which he could assign an age closer than Silurian to Devonian. Another collection from the locality near Sandy Cove was examined by Edwin Kirk, who found that it contained fossils

Leptocoelia sp., *Favosites* sp., and *Coelospira* sp., that probably are of Late Silurian age. Corals from the same area were examined by Jean M. Berdan, who reports that they consist of small heads of *Favosites* sp. and large horn corals intermediate between genera *Triplasma* and *Zelophyllum*. These corals are distinctive, and others have been found on Heceta Island in the southern part of southeastern Alaska where they are associated with brachiopods known to be of Late Silurian age. Miss Berdan concludes that both the generic affinities of the coral and the association of identical corals with the Upper Silurian brachiopods on Heceta Island indicate that the corals near Sandy Cove are probably Late Silurian. On the basis of this rather tenuous and meager evidence, it is suggested that the Tidal formation is of Late Silurian age.

PYRAMID PEAK LIMESTONE

A limestone sequence that overlies the Tidal formation is here named the Pyramid Peak limestone from exposures on the west side of Pyramid Peak. The most complete section of the formation crops out on the lower eastern flank of Black Cap Mountain, 1 mile north of the northern shore of Tidal Inlet; the Pyramid Peak limestone also forms the central part of the northward-trending spur of the 3,082-foot mountain 2 miles southeast of Tidal Inlet. These are the only outcrops of the Pyramid Peak limestone that can be identified with any degree of certainty, and even here the recognition is based entirely on lithology and sequential order. Several other outcrops are believed to contain rocks of Pyramid Peak limestone. One large mass of limestone mapped as part of the Pyramid Peak crops out on the 3,248-foot mountain that stands 2.4 miles east of the southern tip of Composite Island. Other, somewhat similar, rocks crop out on the 3,928-foot peak 1 mile northwest of Mount Merriam in the central part of the D–2 quadrangle, but here the rocks are structurally complex and metamorphosed and were not mapped in detail; they have been grouped on the geologic maps with other rocks as undifferentiated sedimentary rocks of Paleozoic age. A limestone that may belong to the Pyramid Peak limestone composes the southern half of Composite Island; but it could be a part of at least two other limestone formations also, and therefore has not been assigned to any one of them. On the peninsula between Queen and Rendu Inlets is a limestone unit that probably belongs to the Pyramid Peak limestone. Although the rock in this unit is more massive and crystalline than is the rock typical of the Pyramid Peak limestone, the differences are probably caused by thermal and dynamic metamorphism. Furthermore, the overlying rocks are parts of the Rendu and Black Cap formations, which definitely places the massive limestone in the stratigraphic position of the Pyramid Peak limestone.

Another mass of limestone that caps the 4,340-foot mountain south of Mount Wright is mapped as Pyramid Peak limestone. The correlation is based on a similar, but not identical, lithology, and on the fact that the limestone overlies the Tidal formation. Just to the east, outside the mapped area, this limestone mass is in contact with a small segment of the Black Cap limestone, which is known in other localities to overlie the Pyramid Peak limestone.

The Pyramid Peak limestone is made up mainly of light-colored thin-bedded to moderately thick bedded limestone, but the upper part contains some argillaceous beds interspersed with limestone. The basal part grades into a succession of dark-gray to nearly black thin-bedded limestone 300 to 500 feet thick. Beds of the Pyramid Peak limestone range in thickness from 1 inch to 3 feet, but most of the rock is made up of beds 2 inches to 1½ feet thick.

The contact between the Pyramid Peak limestone and the overlying Rendu formation is placed where the thin-bedded limestone succession changes to an interbedded argillite and limestone succession. The contact is gradational, but is sharp enough to be determined within 50 feet stratigraphically. The lower contact between the Pyramid Peak limestone and the Tidal formation is also drawn on a change in lithology, but here some suggestion of a slight angular unconformity exists. (See p. K15.)

The thickness of the Pyramid Peak limestone has not been measured directly; calculations, however, based on the attitude and outcrop width of apparently normal sections indicate that the formation is 2,200 feet thick, which is consistent with estimates made of sections in other parts of the area.

RENDU FORMATION

The sequence of thin-bedded argillaceous and calcareous sedimentary rocks overlying the Pyramid Peak limestone is here named the Rendu formation. A typical section crops out on the southwest flank of the 2,978-foot mountain east of Rendu Inlet. The formation has also been recognized along the east side of the northward-trending range of mountains that contains Black Cap Mountain and in the area northeast of Mount Merriam. A mass of interbedded limestone and argillite that crops out on the 3,248-foot peak 2.4 miles east of the southern end of Composite Island may belong to the Rendu formation. Rocks of the Rendu formation crop out on the west, north, and northeast sides of Sentinel Peak east of Rendu Inlet.

Although the formation consists mainly of thin-bedded limestone and argillite, some of the argillaceous strata are limy and many of the limestone strata contain argillaceous material. Beds range in thickness from a fraction of an inch to slightly less than a foot. No

single figure can be given for the most common thickness, because thicknesses vary from one part of the section to another. In certain parts strata ½ to 1 inch thick are dominant; in other places the thickness ranges from ¾ to 1½ inches. The formation seems to be incompetent, and in the areas where tectonic forces have been active, the rocks are intricately folded. The rocks also are sensitive to thermal metamorphism, and apparently even relatively slight increases in temperature are enough to change them into a fine-grained hornstone that resembles chert. In many outcrops, the rock shows a variety of colors including brown, red, yellow, green, blue, black, and white. These striking colors together with the intricate folding give the formation a distinctive and unusual appearance. Figures 5 and 6 show several phases of this rock.

The Rendu formation resembles the Tidal formation, and in many places the two cannot be distinguished on lithology alone, particularly where the rocks have been thermally metamorphosed. The Rendu formation contains thinner strata that apparently are more highly colored when metamorphosed than those of the Tidal formation; also, the Rendu formation contains a higher proportion of limestone. There appear to be no other readily discernible diagnostic features, and isolated bodies of the Rendu formation may be confused with those of the Tidal formation. For these reasons the sequence of thin-bedded calcareous and argillaceous rocks cropping out along the south side of Morse Glacier could not be definitely assigned to either formation.

The contact between the Rendu formation and the overlying Black Cap limestone appears to be unconformable, but unconformity could not be positively proved. The contact between these formations was followed for several miles along the ridge that includes Black Cap Mountain, and also was seen on the northeast side of Mount Merriam and on the mountains east of Rendu Inlet. In all these areas there seems to be some angular relation between the two formations; although the contact is complicated by faulting, it everywhere seems to have an angular discordance which indicates that the contact is unconformable. Certain other evidence also indicates an unconformity. On the mountain east of Rendu Inlet the formation seems to thin markedly from a section 2,500 feet thick at the northern end to one of about 1,300 feet at the southern end; and although this area is known to contain large faults, which conceivably could account for this marked change in thickness, none could be recognized at the contact. It is therefore most probable that the thinning is due to erosion of the Rendu formation before the Black Cap limestone was deposited.

One of the least disturbed and best exposed sections of the Rendu formation crops out on the east side of Black Cap Mountain. This

section seems to have a thickness of about 2,000 feet. Another section of about the same thickness crops out on the mountain east of Rendu Inlet.

FIGURE 5.—Rocks typical of the Rendu formation and the graywacke-limestone unit. An outcrop containing rocks typical of the Rendu formation which commonly are structurally weak and intricately folded. Limestone and argillaceous limestone make up the bulk of the layers.

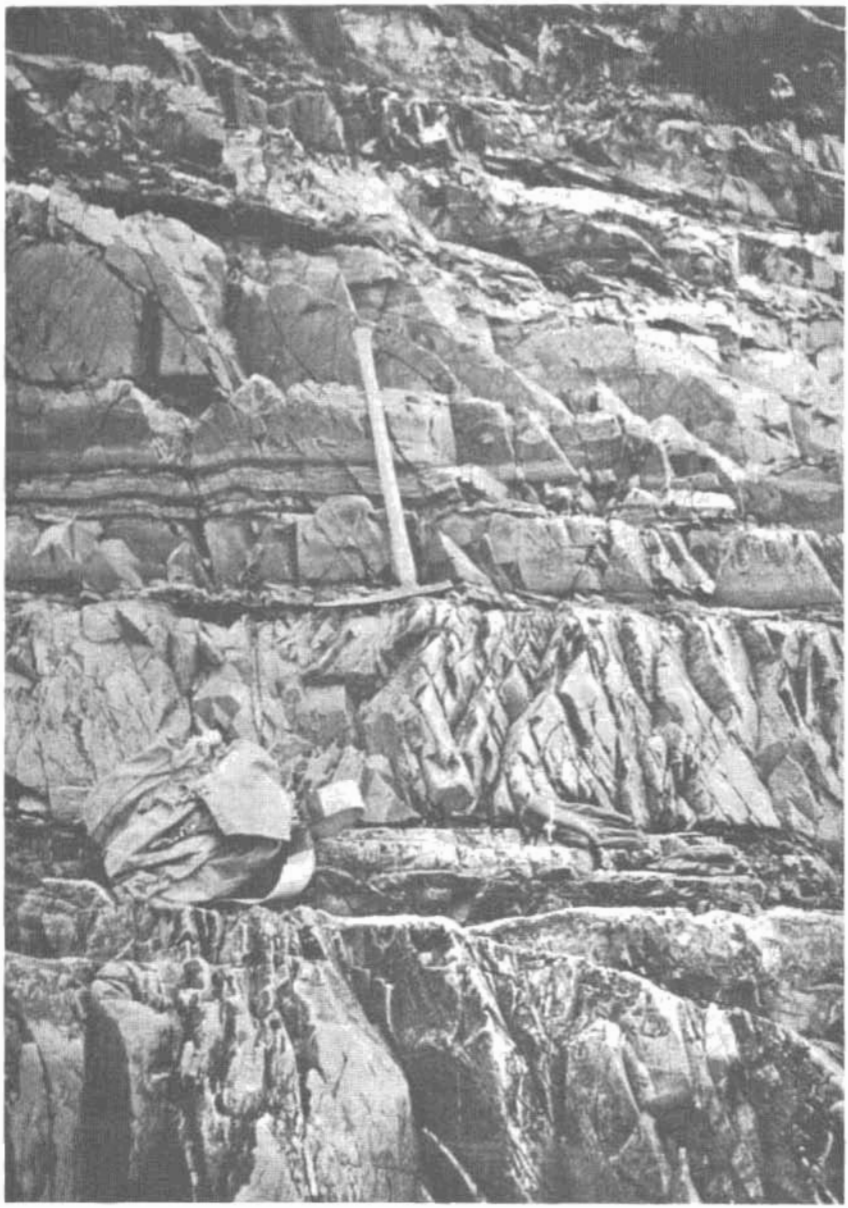

FIGURE 6.—Typical succession of graywacke and limestone in the graywacke-limestone unit of the Rendu formation.

No fossils have been found in the Rendu formation, and its age remains unknown. The formation lies below the Black Cap limestone which is of Middle Devonian age, and must therefore be older than the Black Cap limestone. The Pyramid Peak limestone, which underlies the Rendu formation, is also unfossiliferous; the next lower formation, the Tidal, is tentatively regarded as Late Silurian age. At present the age of the rocks in the Rendu formation and the Pyramid Peak limestone is not known closer than the interval between Late Silurian and Middle Devonian.

BLACK CAP LIMESTONE

A limestone sequence that overlies the Rendu formation is here named the Black Cap limestone from exposures on Black Cap Mountain. Within the mapped area there is no single complete section of Black Cap limestone. A thick, but structurally complex section crops out on Black Cap Mountain; other thick, but relatively inaccessible, successions of Black Cap limestone make up Mount Merriam and the 4,277-foot peak 1.5 miles southwest of it. A thick succession of Black Cap limestone is well exposed in a westward-facing cliff that extends between these two mountains. The formation crops out on the peninsula between Rendu and Queen Inlets, in the area west of Hugh Miller Inlet, and along the east edge of the mapped area east of Muir Inlet. Several other segments of the Black Cap limestone crop out in the adjacent Juneau D–6 quadrangle. Two masses lie near the western and southwestern ends of Adams Inlet, and another crops out on the eastern flank of the ridge just northeast of Sandy Cove. A similar rock unit is widely distributed in the north-central part of the C–2 quadrangle.

The rock in the formation changes markedly in appearance through the sequence. At the base it is thin-bedded black limestone which becomes progressively lighter colored and thicker bedded upward. (See figs. 7–9.) Where metamorphosed, the black limestone generally retains its black color, some of its internal structure, and recognizable fragments of fossils. Upon metamorphism rocks in the upper part generally become more massive and show virtually no evidence of bedding; fossils are generally scarcely discernible. Where possible, the upper and lower parts have been differentiated on plate 1.

The section of the Black Cap limestone is incomplete, and the upper contact has not been recognized. Because all the sections exposed are structurally complex, an estimate of the thicknes can be little more than a guess. The cliff southwest of Mount Merriam contains a se-

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quence that has an estimated thickness of 3,000 feet. The southern flank of Black Cap Mountain contains a section that is nearly 4,000 feet thick. Other higher parts of the formation crop out east of Muir Inlet, and probably altogether the Black Cap limestone has an exposed thickness of about 4,500 feet. The light-colored upper part making up the bulk of the succession may be as much as 3,800 feet thick; the dark-colored basal part is about 700 feet thick.

The Black Cap limestone contains a fairly abundant marine invertebrate fauna. The best fossils so far found come from the outcrop east of Muir Inlet, although other fairly good fossils have been collected from the formation on Black Cap Mountain, on the 4,277-foot peak 1.5 miles southwest of Mount Merriam, and on the mountain between Rendu and Queen Inlets.

Edwin Kirk has examined various collections of these fossils and concludes that they represent a fauna of Middle Devonian age.

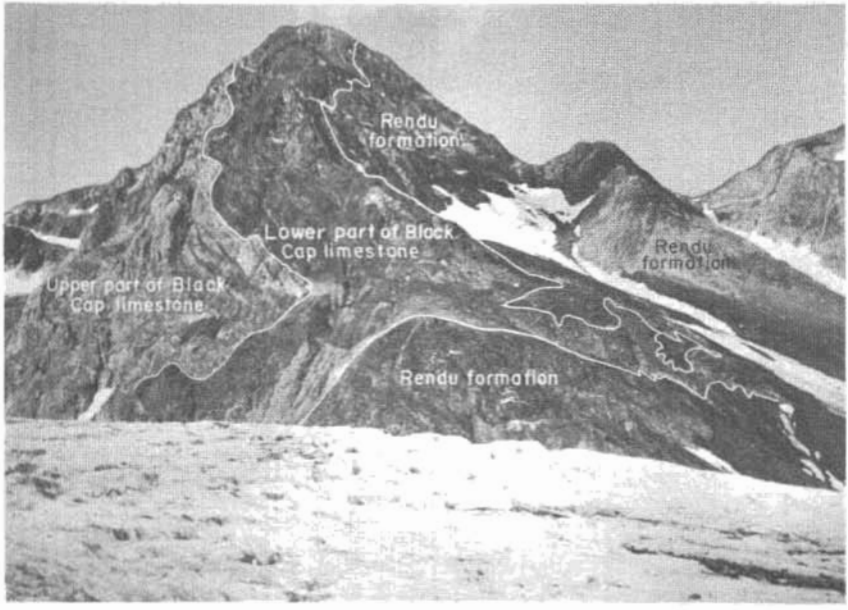


FIGURE 7.—Black Cap limestone exposed in Mount Merriam. Strata shown in this illustration are overturned.

FIGURE 8.—A detailed view of the lower part of the Black Cap limestone. Most of the rock in photograph is limestone.

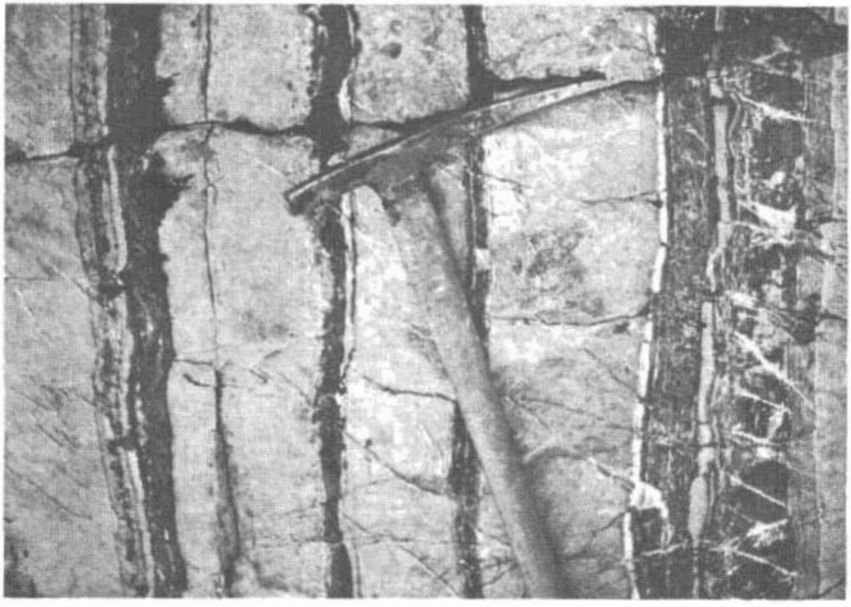


FIGURE 9.—Rock from the central part of the Black Cap limestone. This rock represents a transitional phase between the dark-colored thin-bedded basal limestone and the light-colored massive upper limestone.

ISOLATED BODIES OF SEDIMENTARY ROCKS

Some sedimentary rocks whose age and stratigraphic position could not be determined are present in the mapped area. One group of such sedimentary rock crops out just west of the entrance of Tidal Inlet; another underlies the area bordering on Berg Bay in the B–1 and C–1 quadrangles; a third group lies just east of Muir Inlet in the D–1 quadrangle. These rocks, except those cropping out west of the entrance to Tidal Inlet, are shown on plate 1 as undifferentiated sedimentary rocks.

Sedimentary rocks west of Tidal Inlet.—A graywacke and limestone succession of unknown age underlies an area of about 1 square mile west of Tidal Inlet. The rock consists of thin- to medium-bedded sandstone, graywacke, and limestone. Figure 6 shows a typical outcrop of this rock. The beds range in thickness from less than one inch to several feet; in general the sandstone and graywacke beds are thicker than the limestone beds. The sandstone and graywacke show well-developed lamination, crossbedding, and ripple marks, but the limestone has little internal structure.

The rocks dip fairly uniformly to the east at low angles, but they are cut by several faults. From calculations based on the width of the outcrop and attitude, it appears that a stratigraphic succession about 2,500 feet thick is exposed.

The position of the graywacke and limestone succession in the stratigraphic column is unknown. It is separated from the upper limestone on the west by a major fault; it lies against the massive limestone of the upper part of the Black Cap limestone on the east, but the eastern and western parts of the succession are separated by another major fault. It is shown above the Black Cap limestone formation in the explanation on plates 1 and 2 simply for expediency, and could probably equally well be placed below the Willoughby limestone or below the lowest exposed rocks of the Tidal formation.

Sedimentary rocks near Berg Bay.—Sedimentary rocks that crop out west of Berg and Fingers Bays may belong in part to the formations described previously. However, the sedimentary rocks in the Berg Bay area are so heavily covered that they could not be examined in much detail, and on the basis of present information cannot be definitely correlated with those found farther north (pl. 1). The thickest known succession makes up the ridge south and southwest of Berg Bay, and another well-exposed succession crops out on the southern shore of Lemesurier Island. In other places the rocks are found only in small isolated outcrops.

The succession several thousand feet thick on the mountains southwest of Berg Bay consists, from base to top, of five conformable units: an argillaceous hornstone, an argillite-limestone sequence, a thin-

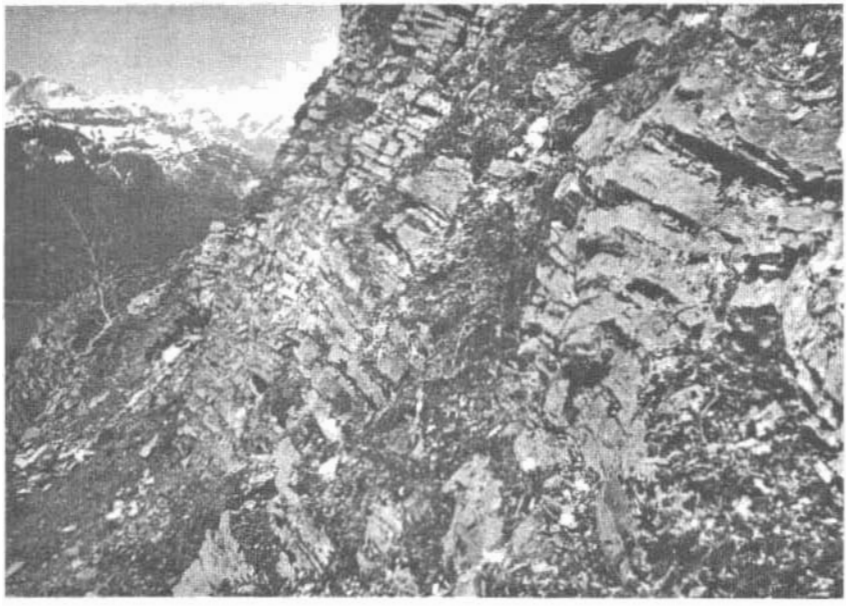
bedded gray limestone, a dark gray limestone, gray thin-bedded limestone, and a gray limestone. Gray limestone-argillite and graywacke that crops out on the point 0.7 of a mile southeast of Berg Bay probably is stratigraphically higher than the rocks mentioned above. Lithologically some of the units are similar to some of those found farther north in the D–1 and D–2 quadrangles, but no correlation between the two groups of rocks is suggested. Figure 10 shows typical outcrops of these rocks.

The uppermost part of the sequence, the gray limestone-argillite and graywacke, bears some resemblance to the sedimentary rocks found in the Sandy Cove area which may be part of the Tidal formation. If this correlation is correct, then all the sedimentary rocks found in the Berg Bay area probably belong to that part of the succession that lies above the Willoughby limestone and below the lowest part of the Tidal formation exposed farther north.

Sedimentary rocks at Goose Cove and "The Nunatak."—Sedimentary rocks several hundred feet thick crop out on the east side of Muir Inlet at Goose Cove and on the 1,205-foot hill called "The Nunatak." The rocks at Goose Cove, which are flat-lying and fairly thick-bedded, are composed of tuff interbedded with some limestone. They range from nearly white to light gray in color; in places they have a greenish hue. The beds average about 3 feet thick, and have no internal structure. Although the bedded rocks at "The Nunatak" are metamorphosed, they probably are part of the succession that crops out at Goose Cove.

The rocks seem to be unfossiliferous, and their age is not known. Because these rocks appear to be the least indurated and the least deformed, they may be younger than any of the other sedimentary rocks found within the mapped area. Twenhofel (1946) tentatively suggests that the rocks are Paleozoic, possibly of Middle Devonian age. The present writer found no further evidence pertinent to their dating, and they are shown on plate 2 as undifferentiated sedimentary rock.

Stratified rocks near Taylor Bay.—Stratified rocks, probably of Mesozoic age, crop out east of Taylor Bay in the southern part of the B–2 quadrangle. They are similar to the interbedded volcanic and sedimentary rocks on northern Chichagof Island which have been described in some detail by Reed (1939) and by Rossman (1959). Definite correlation of specific formations has not been made. The rocks that crop out east of Taylor Bay are similar to, and on strike with, bedded rocks on the George Islands, on Three Hill Island, and on Althorp Peninsula; those west of Taylor Bay are, in general, similar to those found on the east side and probably are part of the same general sequence.



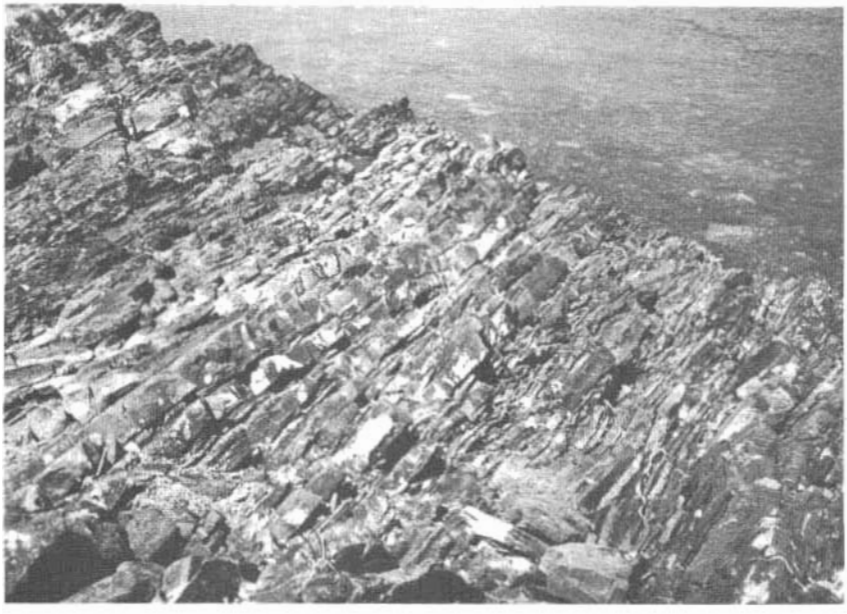


FIGURE 10.—Sedimentary rocks near Berg Bay. Upper, thin-bedded dark-gray limestone, near the top of the stratigraphic succession. Lower, a gray limestone-argillite and graywacke succession 0.7 mile southeast of Berg Bay.

The rocks are dark colored, and generally consist of dark-gray beds (graywacke) interstratified with dark-green beds (greenstone); the graywacke beds are, as a rule, thinner than the greenstones. The graywacke contains fragments of rounded grains of quartz and plagioclase and small fragments of older rocks. The dark color is due to carbonaceous material and graphite. Internal structures include cross-bedding and graded bedding.

The greenstone consists of volcanic material, both ash and lava, and is generally massive.

SURFICIAL DEPOSITS

Much of the mapped area is covered by surficial deposits. Most of the low-lying flat areas and the lower mountain slopes are covered with glacially derived material. In the southern part of the mapped area, near Dundas Bay, the larger river valleys are filled with glacial deposits that consist of both outwash and morainal material. Glacially derived gravels are also abundant near Muir Inlet. Streams have cut into and removed material from some of these deposits, exposing sections of gravels several hundred feet thick; probably the total thicknesses are considerably more, for the bottoms of the deposits are not exposed.

The surface of the gravel deposits in the area adjacent to Muir Inlet is virtually the same as it was when the ice left it, and shows nearly an exact replica of the under surface of the ice sheet. There has been very little deformation or erosion of these gravel deposits since the last glacier overrode them. About the only evidence of abrasion or erosion that can be seen today is found in small straight ridges of gravel, several inches high, which lie in the lee of boulders half imbedded in the surface of the unconsolidated gravel deposits. Gravels that fell to the bottom of crevasses now stand out as ridges on the surface of the gravel plain, and large boulders are scattered over the surface, where they were deposited by the melting ice.

The glacially derived gravels also cover the mountain slopes up to altitudes of 2,000 feet. They give the impression of being plastered onto the mountain sides. Even at their upper limits these deposits may be several tens of feet thick; but they thicken toward the base of the mountain, where they probably average several hundred feet.

In places glaciers dammed the heads of valleys and formed glacial lakes. Clay deposited in one of these lakes lies beneath the gravels between Muir and Adams Inlets. One lake formed in the valley above Bear Track Cove, and a small glacially dammed lake lay in a small valley in the upper part of Bartlett River.

Preglacial forests of two and possibily three ages are preserved in the gravels in many parts of the Glacier Bay area. Two forests can be seen, one on top of the other, east of Goose Cove on the east side of Muir Inlet.

Carbon-14 dating of carbonaceous material from the preglacial forests has been of considerable aid in unraveling the recent glacial history of the Glacier Bay area (Seitz, 1959). The forests were killed when covered by outwash gravels deposited ahead of the glaciers. Seitz (1959) suggests that 3 advances have taken place—7,000, 4,000, and less than 500 years ago. These dates appear fairly reasonable, but the data are too few as yet to draw any firm conclusions. Some of the figures on ages obtained on some of Seitz' samples do not agree with the above listed figures, and the reason for the discrepancies is as yet unexplained.

IGNEOUS ROCKS

Igneous rocks crop out in relatively large areas in the western and northern parts of the mapped area. Diorite is most widespread. It crops out as far south as central Baranof Island and extends northward into Canada where it is believed to connect with the diorite that makes up the main part of the Coast Range batholith. Quartz diorite is also widespread and may be a late phase of the diorite. Other igneous rocks within the mapped area include granite, gabbro, and dike rocks.

DIORITE

The diorite is largely confined to the western and northern parts of the mapped area, but small stocks crop out just outside the quadrangle boundaries. One stock covers an area of about 4 square miles just south of Tidal Inlet, one covers about three-fourths of a square mile 4½ miles west of Sebree Island, and another small stock crops out at Sandy Cove. Sturgess Island, near the southeast corner of the D–1 quadrangle, is partly composed of diorite.

In general the rock mapped as diorite in the Dundas Bay area is darker colored and has a more mafic composition than the rock between Muir and Queen Inlets. Furthermore, the diorite in the northern part of the area shows more evidence of active intrusion than that found farther south near Dundas Bay. It is not known how the diorite in the two areas is related; but inasmuch as there is no evidence that the diorite bodies in the two areas are of different ages, they have all been included on the geologic maps as one rock unit.

The diorite is light gray to nearly white, and has a granitic texture. The main rock-forming minerals are plagioclase, hornblende, biotite, and quartz. Generally the rock has a moderately well developed fabric, formed by a subparallel alinement of the hornblende and plagi-

oclase crystals. In certain areas the diorite contains inclusions, which in places are exceedingly abundant and compose one-fourth to one-half of the rock by volume. Rock containing these inclusions crops out on the small islands south of Blue Mouse Cove near Hugh Miller Inlet. The inclusions are now found in all stages of assimilation; they range from inclusions of sedimentary and igneous rock only moderately metamorphosed to others so completely recrystallized that they are barely distinguishable from the diorite. The inclusions have varying shapes and degrees of angularity. The largest inclusions may be as much as several feet in diameter; commonly a large block may have broken into several smaller ones. In some outcrops the corners of the fragments from the broken blocks have been assimilated by the magma. In other places the broken inclusions appear to have been replaced by stringers and dikelike masses of igneous rock without apparent displacement of the several parts (figs. 11, 12).

The inclusions commonly are so alined that their longest directions are subparallel both to each other and to the fabric of the enclosing diorite. Seitz also has described these inclusions in his report on the C–2 quadrangle (Seitz, 1959).

The plagioclase in the diorite ranges in composition from oligoclase to labradorite, but most of it is andesine. In thin section the plagioclase commonly shows few or no crystal faces (subhedral or anhedral, respectively), but rock from certain areas contains plagioclase crystals that clearly show crystal faces (euhedral) in lath-shaped or rectangular crystals. Oscillatory zoning is relatively common, and twinning is generally well developed and sharp. Alteration is moderate and consists mainly of saussuritization.

The hornblende is most commonly somewhat elongate and subhedral. Generally hornblende has engulfed small grains of plagioclase, quartz, and opaque minerals as it grew, giving it a poikilitic or sieve structure. The hornblende is associated with biotite in such a way that the latter appears to be developing from the former.

The quartz was the last mineral to crystallize and is everywhere anhedral. As seen in thin sections, quartz commonly seems to have replaced the plagioclase.

The diorite is known to intrude rocks of Mesozoic age on Chichagof Island and is therefore younger than those rocks. Reed (Reed and Coats, 1941, p. 40) concluded in his report that the diorite was formed in Late Jurassic or Early Cretaceous time. He points out, however, that the intrusion of magma which formed many of the large and small masses of igneous rock, now collectively called the Coast Range batholith, may well have occupied a considerable length of geologic time, and that locally, age relations of the igneous rock may differ slightly.

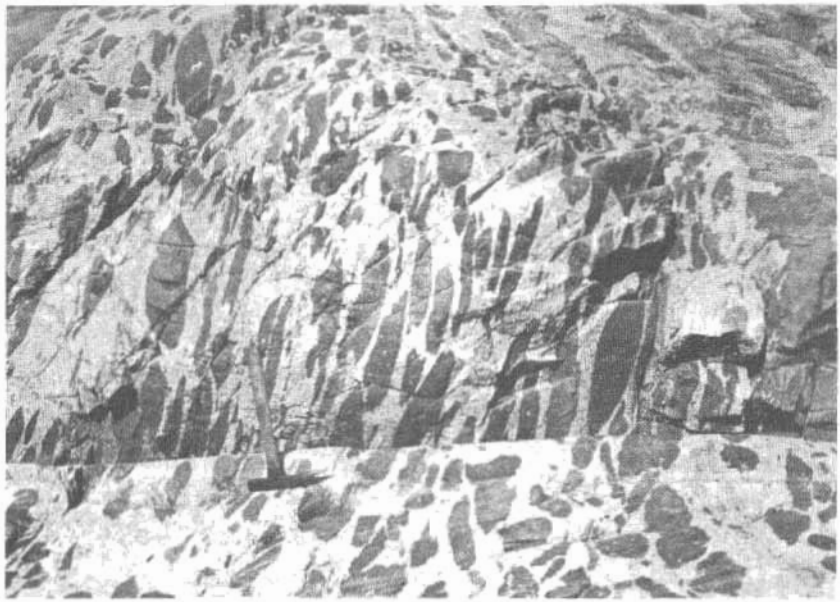
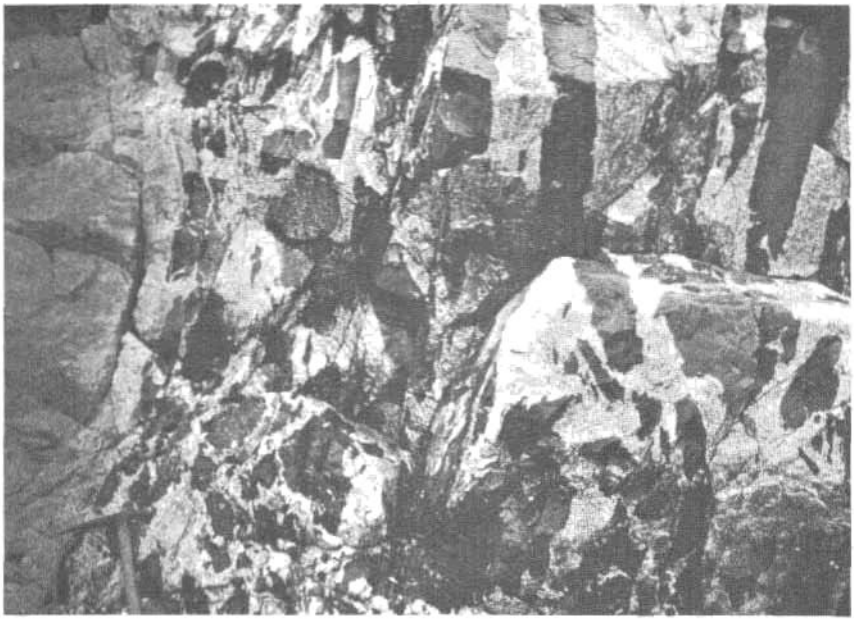


FIGURE 11.—Inclusions of dark rock believed to be recrystallized volcanic material in diorite, Hugh Miller Inlet. Relations of inclusions to diorite show that both active intrusion and replacement of dark rock by diorite have taken place. Dark inclusions probably represent later additions to the melt and hence are not so thoroughly "digested."



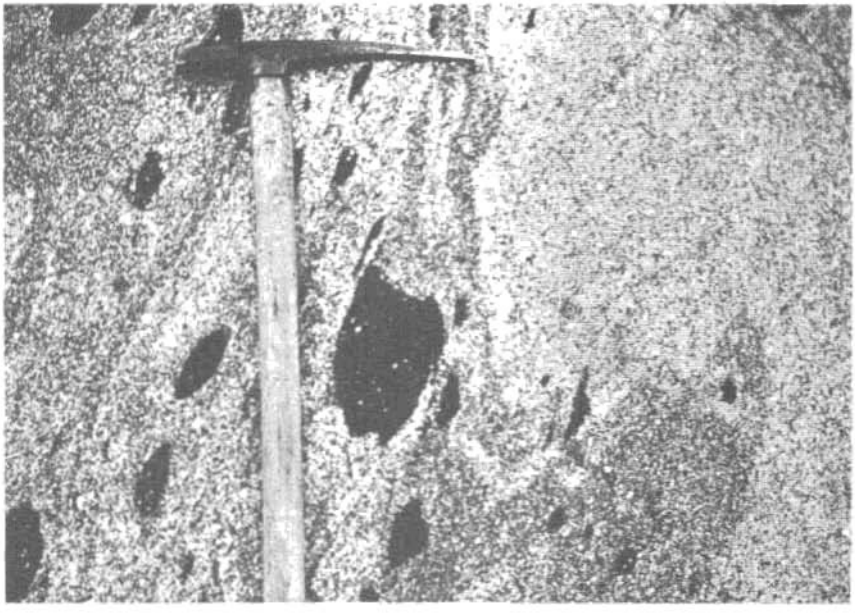


FIGURE 12.—Inclusions of dark rock believed to be recrystallized volcanic material in diorite, Hugh Miller Inlet. Relations of inclusions to diorite show that both active intrusion and replacement of dark rock by diorite have taken place. Lower figure shows inclusions in gneissic diorite; conceivably the faintly darker bands are recrystallized older rock that has been differentially moved and smeared out. The dark inclusions probably represent later additions to the melt and hence are not so thoroughly "digested."

QUARTZ DIORITE

Quartz diorite crops out on Lemesurier Island, east of Dundas Bay, and on the mountains east of Rush Point. Another body of quartz diorite crops out on the mountains in the southeast corner of the B–2 quadrangle, but the relation of this quartz diorite to that found in the eastern part of the B–1 quadrangle is not known.

It is known that the quartz diorite is younger than the diorite, from the contact relations observed along the northern shore of Chichagof Island, 2 miles east of Gull Cove; the diorite and quartz diorite, however, may not differ much in age, and possibly the quartz diorite may be a late phase of the diorite.

In outcrop the quartz diorite is lighter colored and has a less well developed fabric than the diorite. The plagioclase ranges from albite to andesine, and the rock contains more quartz and smaller amounts of the ferromagnesian minerals than the diorite. In addition to these differences the rock in places contains as much as 5 percent of orthoclase. Texturally the quartz diorite resembles the diorite. The feldspar tends to form in lath-shaped anhedral to euhedral crystals and shows oscillatory zoning. The hornblende forms in slightly elongate grains and has a well-developed poikilitic structure. The configuration of the contact between quartz and the other minerals suggests that quartz was the last rock-forming mineral to crystallize. In part it probably replaced earlier minerals. There is little or no suggestion of a preferred orientation of minerals in the quartz diorite. The alteration consists of slight saussuritization of feldspar and local replacement of the hornblende by chlorite.

GRANITE

A granitic stock crops out between the east and west arms of Dundas Bay and extends into the C–2 quadrangle, where it has been mapped by Seitz (1959). The rock in the hand specimen is light colored and medium to coarse grained. It contains 30 to 50 percent orthoclase, 50 to 30 percent plagioclase (An 5–25), 15 to 40 percent quartz, and 5 to 20 percent ferromagnesian minerals, chiefly biotite and a small amount of hornblende. In outcrop the rock shows little evidence of preferred orientation of crystals. Contacts with adjacent rocks are sharp, and contact metamorphism is slight.

The granitic rock is less altered than the diorite and is known to intrude the diorite in the C–2 quadrangle (Seitz, 1959); it is therefore younger than the diorite. Nothing more is known about the age of the granitic rock.

GABBRO

One small body of gabbro about 1,000 feet in diameter is exposed 2.3 miles east of Muir Inlet and 3.8 miles southwest of Red Mountain. The roundness of the outcrop as well as some of the petrographic features of the rock suggests that the body was a small volcanic plug. The rock in outcrop is dark red and fairly massive. In thin section, the rock is seen to have a diabasic texture, and small laths of plagioclase (labradorite) make up much of the rock. The optical properties of the pyroxene indicate that it is augite. The pyroxene crystals are anhedral and contain lath-shaped plagioclase crystals. The rock now contains abundant chlorite that is believed to have replaced olivine, but at no place within the section examined were any remnants of olivine recognized. Neither the pyroxene nor the plagioclase is extensively altered, but veinlets of calcite cut the rock and appear to have replaced both plagioclase and pyroxene. The alteration might be due to incomplete interaction between the different phases as the magma cooled, or it might be caused by the assimilation of foreign material that could easily disrupt the chemical processes that were taking place. The calcite in the rock is some evidence that calcareous material has been assimilated. The gabbro intrudes the Black Cap limestone of Middle Devonian age, and is therefore younger; nothing else is known regarding the age of the gabbro.

DIKE ROCKS

Many mafic dikes crop out within the mapped area. Their concentration and number are unusually great, and the total surface area occupied by them probably aggregates several square miles within the D–1 and D–2 quadrangles. The dikes generally are nearly vertical and strike westward. The most extensive dike swarms lie on Mount Wright along the east side of the mapped area. This group of dikes strikes west or slightly north of west and dips steeply. The group is known to continue for several miles to the east of the mapped area. The dikes are exceedingly abundant, and on Mount Wright in one zone as much as half a mile wide, the dikes make up one-fifth to one-third of the total rock. Large numbers of these dikes also crop out on the 3,206-foot mountain near the south end of the peninsula between Muir Inlet and Glacier Bay. Here the dikes are as much as 10 to 20 feet wide and constitute one-tenth to one-third of the total rock in the area. The mafic dikes are also exceptionally abundant on the 3,928-foot mountain 1 mile northwest of Mount Merriam. Here the dikes are well exposed and even from a short distance they appear to be beds of sedimentary rock.

The color of the mafic dikes ranges from dark green to nearly black. Most of the dikes are softer than the country rock and consequently

have been eroded below the general level of the land surface; but certain rocks, such as those making up the Tidal formation, are softer than the dike rock, and in such rocks the dikes stand out as ridges.

Only a few thin sections from the mafic dike rock have been examined; those examined probably are typical of most of the mafic dikes and show the fundamental petrographic features of the rocks.

As seen in thin section, the dike rocks are moderately fine grained and have a diabasic texture. They contain plagioclase, augite, olivine, hornblende, biotite, and chlorite. Alteration of the rock is extensive.

The pyroxene is augite; because of its slightly pinkish color in thin section, it is believed to be somewhat titaniferous. Some of the mafic dikes contain olivine. The plagioclase is labradorite-bytownite (An 70+), which has a mean index of refraction of about 1.57. Two ages of plagioclase are evident, but no large differences were found in their composition. The older plagioclase forms phenocrysts which are generally saussuritized; the younger consists of sharply twinned lath-shaped crystals which are nearly unaltered. The younger crystals have a large length-to-width ratio, and many penetrate the augite. These textural and physical features suggest that the younger plagioclase crystallized after magma had in effect reached its final position, because the large proportion of length to width of the plagioclase renders the crystals so fragile that even slight differential movement of the magma would cause them to break. Such fracturing was not seen in the thin sections examined. The hornblende and biotite seem to have formed from the pyroxene, and later all three minerals and probably plagioclase as well were altered and replaced by chlorite.

The age of these mafic dikes has not been definitely established. They are known to intrude a granodiorite in the area between Reid Inlet and Lamplugh Glacier to the west of the mapped area and are also found to a limited extent within the diorite; but because they are much more abundant in the sedimentary rock than they are in the diorite, it is probable that most of them are older than the diorite. Although the dikes are cut by faults and probably have been involved in some folding, for the most part they cut across the folded rock; this fact indicates that they were intruded after the major period of deformation.

A few light-colored dikes crop out within the mapped area. One of the longest crops out about 1 mile north of Tidal Inlet on the west side of the mountain standing west of Pyramid Peak and extends eastward for at least 7 miles to a point near Muir Inlet. In places this dike splits into two or more subparallel dikes. Generally the dike is 10 to 20 feet wide, but at one place on the east side of Pyramid Peak it is more than 50 feet wide. Other light-colored dikes of similar ap-

pearance crop out between Reid Inlet and Lamplugh Glacier, and similar dikes are found widely but thinly scattered throughout the mapped area.

The light-colored dikes are so fine grained that individual minerals cannot as a rule be recognized in hand specimens. Generally the rock is massive and fractures into subangular pieces. In thin section the minerals composing the dike rock are seen to be mainly plagioclase and quartz; chlorite and amphibole are widely but sparsely distributed through the rock. Commonly the minerals are highly altered and replaced by other minerals. One rock from which a thin section was cut contained abundant iron carbonate, the feldspar was almost completely replaced, and chalcedony veinlets cut the rock.

The light-colored dikes both cut and are cut by the mafic dikes, and probably both are of about the same age. The source of the light-colored dikes is unknown, but they are probably derived from one or more of the many intrusions of Cretaceous age that make up the Coast Range batholith.

METAMORPHIC ROCKS

AMPHIBOLITE

Within the mapped area are metamorphic rocks which have been so thoroughly recrystallized that their original character is no longer discernible. The most abundant type of metamorphic rock is herein called amphibolite, to denote a crystalline rock of medium- to coarse-grained texture that has hornblende as one of its major constituents. Nearly all the amphibolite contains plagioclase which in places makes up more than 50 percent of the rock by volume. The largest area containing amphibolite lies between the west arm of Dundas Bay and Brady Glacier.

Amphibolite is commonly closely associated with the diorite both geologically and geographically, and it is thought that the amphibolite was produced through processes related to the intrusion of the diorite. Metamorphic rocks of much the same type are known to crop out both in the vicinity of Hugh Miller Inlet and farther north near Queen and Rendu Inlets, but the amount of amphibolite found in the northern part of the mapped area is small compared to the amount in the southern part. That in the northern part has not been shown on the geologic map. Much of the metamorphic rock in the C-2 quadrangle is of the type mapped as amphibolite in this report, but Seitz has separated these rocks into several groups, two of which he has designated as the diorite and hornblende-plagioclase rocks (Seitz, 1959).

The amphibolite is varied in texture, grain size, and composition, and probably formed by both recrystallization and replacement. The

amphibolite west of Dundas Bay consists of thoroughly recrystallized older rock that now has a granoblastic texture. Much of this rock is banded and is therefore now a well-foliated crystalline gneiss. Although this gneiss has obviously undergone considerable differential movement that conceivably could have brought about the banding, the fact that at least one limestone bed lies in the gneiss parallel to the bands leads one to believe that the bands are relict beds. Figure 13 shows a typical outcrop of the amphibolite gneiss. The rock shown in figure 13 has been completely recrystallized, but the original bedding is still largely preserved.

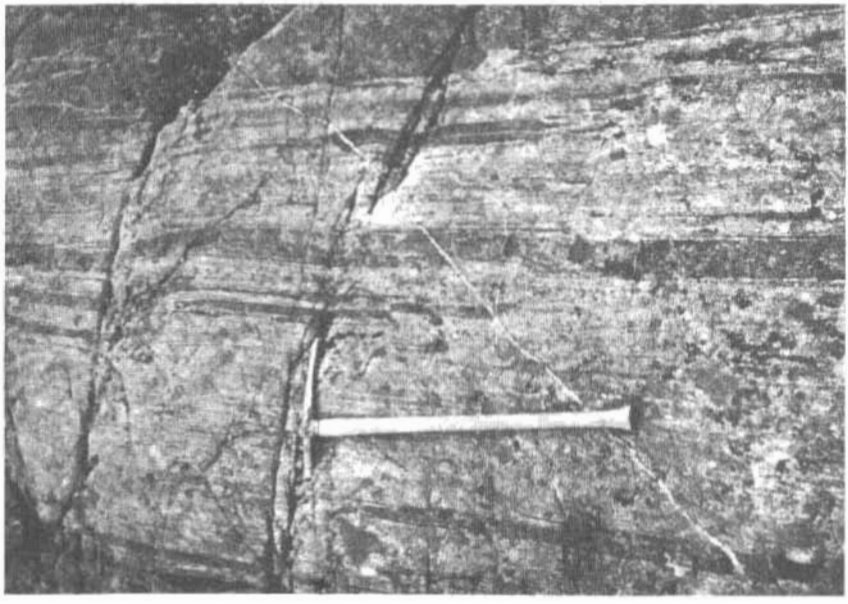


FIGURE 13.—Typical amphibolite gneiss showing banding which may represent original bedding of volcanic and sedimentary rock.

Another type of amphibolite is a dark-colored rock that shows no discernible relict bedding. This rock is herein called massive amphibolite. Figure 14 shows some typical but small outcrops of this rock, which consists almost entirely of hornblende and augite. The massive amphibolite is fairly common and crops out at widely scattered places throughout the zone containing metamorphic rock both west of Dundas Bay and farther south on Chichagof Island. Bodies of massive amphibolite are generally a few inches to a few tens of feet in diameter, but on Chichagof Island massive amphibolite underlies areas several thousand feet in diameter. The massive amphibolite is fairly coarse grained, and crystals range in length from 0.05 inch to several

inches. Generally the crystals within any one small area are all of approximately the same size, and it is difficult and almost meaningless to assign any particular figure to the mean grain size of the massive amphibolite. Because this rock is internally structureless and occurs within zones of well-banded gneisses, it generally appears to cut across and replace the bands.

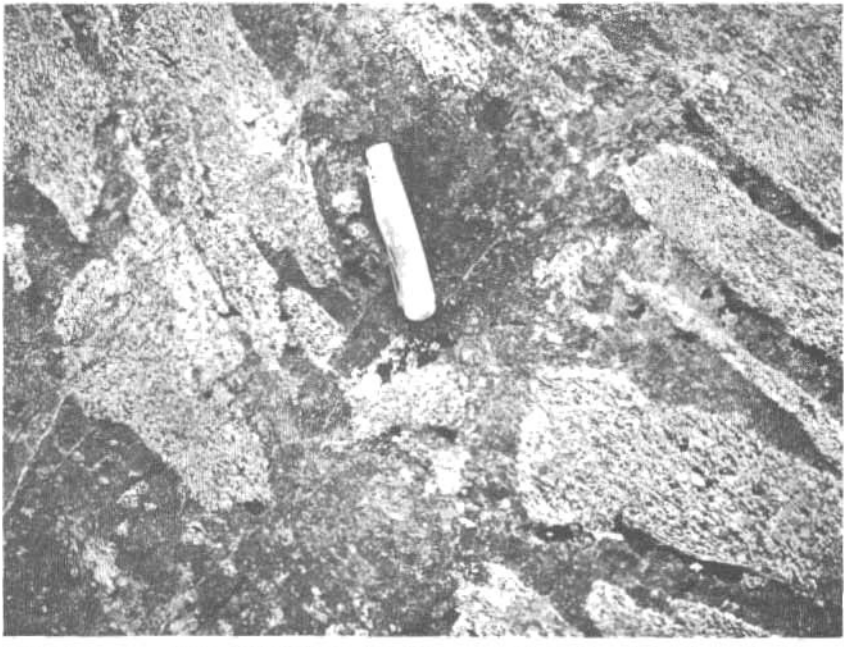
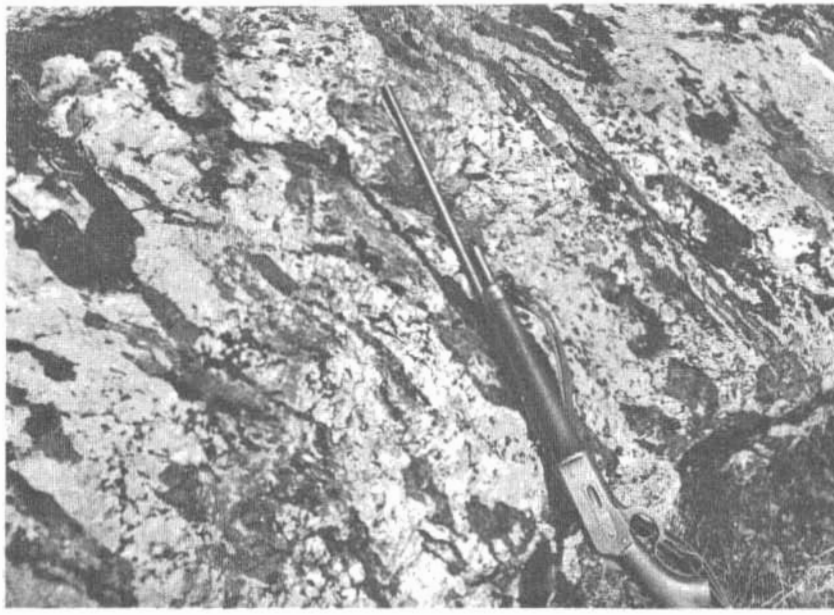


FIGURE 14.—A massive amphibolite replacing amphibolite gneiss. The illustration shows a type of replacement commonly found in the paragneiss. The masses of lighter colored rock are unreplaced remnants of the amphibolite gneiss.

Another type of rock found associated with the massive amphibolite is herein called the hornblende-plagioclase rock, which is a coarse-grained rock composed essentially of elongate crystals of hornblende set in a matrix of feldspar. In places, the crystals are extremely large and the hornblende crystals may be several feet long. Figure 15 illustrates the hornblende-plagioclase rock. This rock crops out only to a limited extent within the mapped area. Some of the best outcrops are on the mountains between Dundas Bay and Brady Glacier, and a few are found on the northern part of the mapped area near the contacts of the diorite. The rock is well exposed on the south shore of the Inian Islands and in the C–2 quadrangle which has been mapped by Seitz (1959). The term "hornblende-plagioclase rock" is also used by him for the same type of rock.



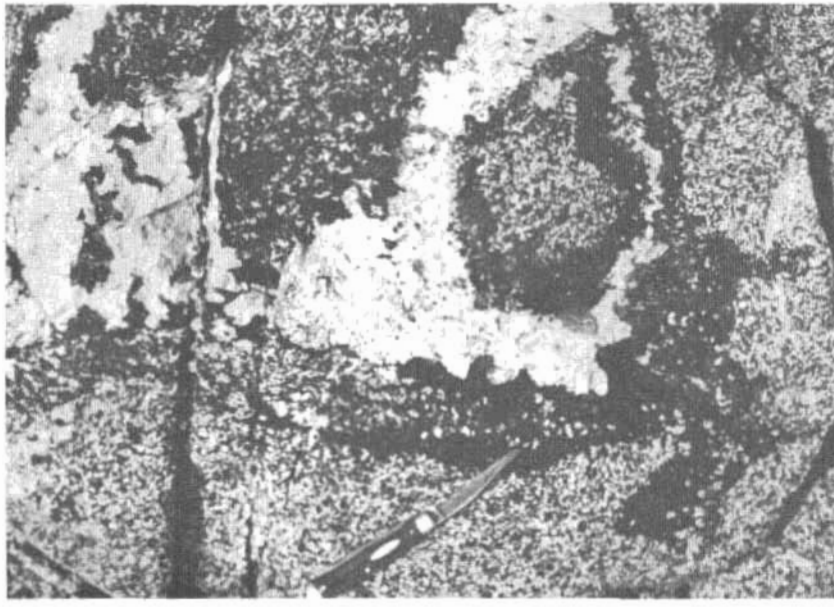


FIGURE 15.—Several phases of the hornblende-plagioclase rock. Upper figure shows an uncommon type of hornblende-plagioclase rock containing skeletal hornblende crystals. All the dark rock is hornblende, generally present in any one place as a single crystal. Several crystals are so exposed that their longitudinal cross section is visible. Lower figure shows a common type of hornblende-plagioclase rock.

The hornblende-plagioclase rock is found in areas of intensive recrystallization. In places it is associated with massive amphibolite, which probably formed under similar metamorphic conditions. As far as is known, none of the hornblende-plagioclase rock retains any traces of structure from the rock that it replaces, and in this respect it resembles the massive amphibolite. Both the hornblende-plagioclase rock and the massive amphibolite may well be derived by fusion, diffusion, and replacement of older rocks, and it is believed that the source of the massive amphibolite and the hornblende-plagioclase rock was largely, if not entirely, the rock in which they are now found. This process has been discussed by Rossman (1959) and by Seitz (1959) and will not be treated further here.

One other type of amphibolite, herein called the garnet amphibolite, is exposed within the mapped area. A large body of garnet amphibolite crops out on the east side of the mountain just west of Dundas Bay and on the west side of the mountain east of the west arm of Dundas Bay. The same rock type extends to the south, making up the western part of the mountain south of Dundas Bay; similar rocks which probably are a part of the same mass, crop out on the George Islands on the east side of Cross Sound. The garnet amphibolite has been highly recrystallized and contains only faint traces of the original rock structure. In many places only the garnet in the rock distinguishes garnet amphibolite from diorite. Because the garnet amphibolite is more crystalline than other types of amphibolite and lies closer to the diorite, it probably represents a higher grade of metamorphism than does the amphibolite gneiss, massive amphibolite, or hornblende-plagioclase rock.

MIGMATITE

A zone containing migmatite dikes and other evidences of migmatization lies between the east and west arms of Dundas Bay. The zone is several hundred feet wide and trends southeastward across the landmass south of Dundas Bay and crosses the Inian Islands. It continues diagonally across the Inian Peninsula and southward across Chichagof Island to a point near the head of Lisianski Inlet, a distance of 45 miles. The continuity of this zone over such a great distance makes it one of the most remarkable metamorphic features so far found either on Chichagof Island or in the Glacier Bay area. The zone terminates on the north against the granite mass that crops out between the east and west arms of Dundas Bay, and the migmatites do not appear to continue north of the granite mass. No extensive work has been done on the migmatites within the mapped area, and only a brief mention of their existence is made in this report. A more complete account is given in an earlier report (Rossman, 1959).

The migmatite zone is found, without exception, in high-grade metamorphic rock, and is made up of a network of light-colored ir-

regular-shaped dikes and small light-colored crystalline rock bodies. Figure 16 shows typical outcrops of the migmatite. In certain areas on Chichagof Island migmatite zones are large, and the amount of migmatitic material becomes so great that the masses are small quartz diorite stocks.

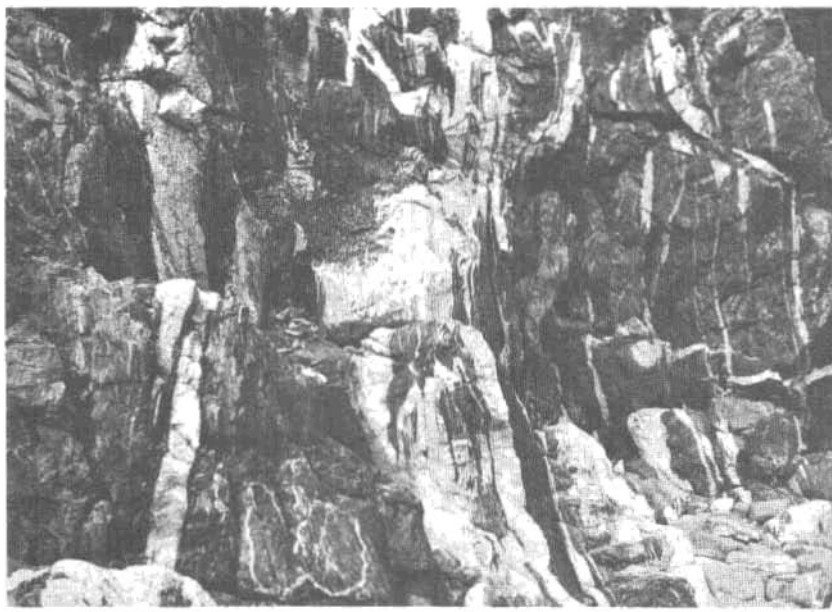


FIGURE 16.—Migmatite dikes formed in paragneiss. This zone of migmatization is approximately a thousand feet wide and extends southward across Chichagof Island to near the head of Lisianski Inlet—a distance of more than 45 miles. Photograph taken on the north-central part of the Inian Islands, B-2 quadrangle.

Because the migmatite dikes in places contain faint but recognizable traces of bedding which is continuous with that of the enclosing country rock, it is believed that migmatites do in part replace the rock in which they lie. This is not true everywhere, however; in certain areas some of the migmatites are true injected rock. It is probable, therefore, that both replacement and injection of migmatitic material take place within this zone of migmatization. Furthermore, the writer is of the opinion that much of the material composing the migmatite has formed from the host rock.

The migmatite in thin section can be seen to consist essentially of plagioclase (oligoclase) and quartz. Other minerals include sphene, chlorite, calcite, and light-colored mica. The feldspar and quartz are both anhedral, and where they are in contact, they generally have sutured borders. The minerals have undergone considerable cataclastic deformation (mechanical crushing). Locally, minerals from

the host rock lie within the migmatitic rock, and where this has been observed, the older crystals appear to be attacked and partly replaced by the migmatitic material.

The migmatites on Chichagof Island and near Dundas Bay are in rocks that probably are of Mesozoic age. It is believed that the migmatites are almost certainly related to the metamorphism associated with the formation of the Coast Range batholith.

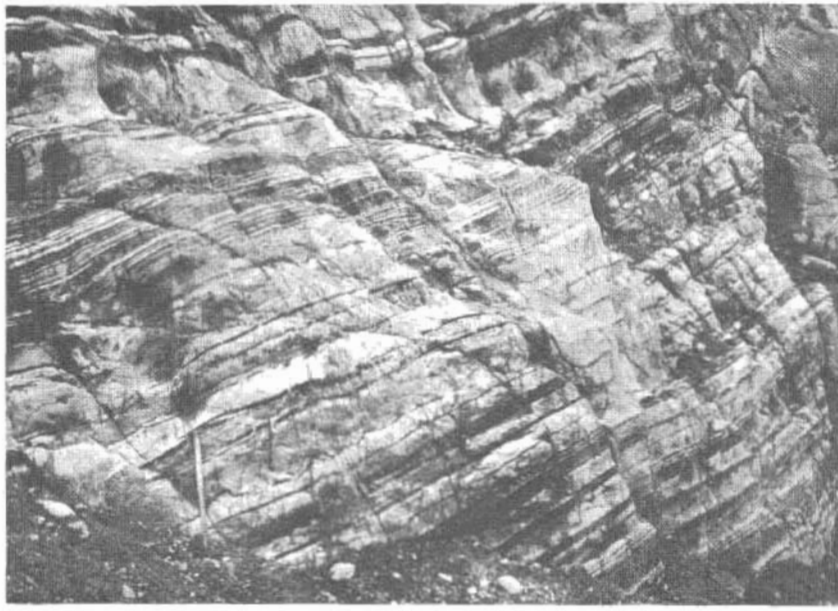
TACTITE

In an area 1 to 2 miles south of Mount Merriam, an extensive zone of metamorphosed rock (tactite) has developed where the diorite has come in contact with limestone. This contact zone has been examined in only a few places, but float from it is widely scattered over the surface of Twin Glacier and the outwash plain below the glacier.

The minerals so far noted in this zone include green, yellow, and brown epidote, wollastonite, blue and white calcite, brown and yellowish-brown garnet, green and brown idocrase (vesuvianite), quartz, green mica, diopside, anthophyllite, and several other nonmetallic minerals that were not identified. Locally the rock contains metallic minerals, including pyrite and galena. Faint copper stains were also observed. X-ray spectrographic analysis shows that the rock contains arsenic, manganese, and strontium as well as the elements in the minerals listed above. Epidote and idocrase crystals are in places several inches long; commonly they are imbedded in blue calcite and many hand samples are so striking in appearance that they may have some value as collectors' specimens. Some of the samples were immersed in diluted hydrochloric acid which dissolved the calcite and left beautiful clusters of well-developed crystals of epidote, diopside, garnet, and idocrase. Not all these minerals were present in any single specimen, however.

HORNSTONE

At many places in the northern part of the mapped area the argillaceous (clay-bearing) sediments have been thermally metamorphosed to a dense, hard rock called hornstone. Both the Tidal and Rendu formations contain argillaceous material and consequently the rocks in both formations are particularly susceptible to this type of metamorphism. Hornstone derived from rocks of the Tidal and Rendu formations crops out on both the east and west sides of the mountain standing to the east of Rendu Inlet; along the west side of Black Cap Mountain; on the north side of the mountain range that stands directly south of Morris Glacier; in the Wachusett Inlet area; on Minnesota Ridge; and on the end of the peninsula between Glacier Bay proper and Muir Inlet. Small amounts of hornstone also occur in other areas. Figure 17 shows outcrops of the hornstone.



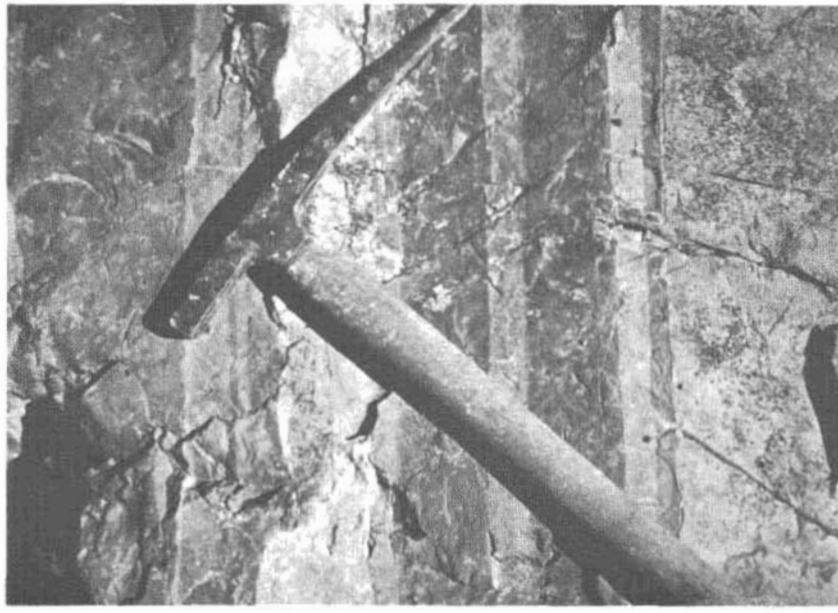


FIGURE 17.—Hornstone formed from clay-rich siltstones. The rock in outcrop is dense and typically highly colored. The beds shown contain purple, green, brown, yellow, near-white, and near-black beds.

Generally the metamorphism that forms the hornstone is of sufficiently high grade to give the original rock a new color and render it dense and hard. In outcrop the hornstone is highly colored and includes most hues and shades of the primary colors. The original structures of the beds and internal structures within the beds are faithfully preserved; in places the metamorphism has accentuated the internal structures, which are more easily seen in hornstone than they are in the original rock. Because the hornstone has formed predominantly in rock of the Tidal and Rendu formations, which are both fairly thin bedded, the hornstones are likewise generally thin bedded. The Rendu formation contains limestone interbedded with argillaceous rock: this limestone upon metamorphism is recrystallized, but looks about the same as it did before recrystallization.

STRUCTURE

The bedded rocks in the northern part of the mapped area do not have any well-developed regional trend of folding. Possibly this lack of regional trend is the result of their having undergone more than one period of deformation, and certainly it is partly due to the proximity of the large intrusive diorite batholith that crops out in the northern and western parts of the mapped area. In general, the bedded rocks near the diorite are folded so that the axes of the folds tend to be parallel to the contact. (See pl. 2, sections *G*, *H*, *I*, *J*.) Elsewhere in the D–1 and D–2 quadrangles the axes of the folds commonly have a northwesterly trend, but this trend also probably is due to compressive forces brought on by the intrusion of the dioritic batholith more than to a regional northwesterly structural trend. The bedded rocks in the central part of the mapped area centering around Willoughby Island are less folded than are the rocks in adjacent areas, but unfortunately most of the rock in this area has been eroded below sea level and only isolated bits of structure and stratigraphy can be observed. This zone of moderate folding appears to extend southeastward to the northeastern part of Chichagof Island where the sedimentary rocks of Paleozoic age have reasonably continuous and moderate structures.

Because few generalizations can be made concerning the structure within the mapped area, it is not deemed worthwhile to discuss the structures at length because such a discussion would of necessity deal almost entirely with highly complex and local conditions. What is known of local structures is shown on plates 1 and 2, to which the reader is referred for information on the structure of specific areas.

The rocks throughout the mapped area are cut by faults, many of considerable extent and large displacement. The faulting, like the folding, is more intense near the diorite. The faults are particularly

strongly developed in the D–1 and D–2 quadrangles. A series of subparallel eastward-trending faults lies south of Morse Glacier and between Muir Inlet and Glacier Bay. These faults are parallel to the diorite contact, and those nearest the diorite have the greatest displacement.

Faults are strongly developed in the rocks of Mount Wright. Their general easterly trend suggests that they are related to those farther west; but on Mount Wright the faults are more irregular in trend and dip, and several appear to be thrust faults. Probably the faults on Mount Wright formed during the intrusion of the diorite, possibly during earlier Mesozoic time, when the major synclinal basins were forming to the east and west.

Faults are less numerous in the southern part of the mapped area, but those shown on plate 1 are of strong displacement and considerable structural significance.

Other smaller faults, many scarcely more than well-developed joints, cut the crystalline metamorphosed rocks and the diorite of the mapped area. These minor faults have little apparent structural significance.

GEOLOGIC HISTORY

Marine deposition seems to have been fairly continuous from the Middle Silurian through the Middle Devonian; if the land surface did rise above sea level, apparently it was for only short periods of time, because no large unconformity is known to exist in this part of the sequence. From other investigations in southeastern Alaska it is apparent that through most of the Paleozoic era the area that is now southeastern Alaska was submerged beneath the sea and both marine sedimentary and volcanic rocks were deposited. At intervals the land rose above the sea and erosion took place, as is attested by the unconformities and disconformities found within the Paleozoic sequence (Buddington and Chapin, 1929, p. 39–45).

Little is known concerning the geologic history of the interval between Late Silurian and Middle Devonian in southeastern Alaska; but a thick sequence of almost unfossiliferous sedimentary rocks may have been deposited during this time. This sequence is believed to be represented in the mapped area by the Tidal formation, Pyramid Peak limestone, and Rendu formation which lie stratigraphically between the Willoughby limestone of Late Silurian age and the Black Cap limestone of Middle Devonian age. Although the first 3 formations have a total thickness of more than 16,800 feet, they are unfossiliferous; this lack of fossils would prevent early recognition of their age.

Although the evidence for uplift in the central part of southeastern Alaska is not complete, it is thought that by the beginning of the Mesozoic era the rock was uplifted above sea level and parallel

geosynclinal troughs developed along the west coast and along a line extending from Haines southeastward as far as the southern end of southeastern Alaska. Both these geosynclinal troughs were seats of extensive deposition, and thick successions of sedimentary and volcanic rock were deposited in them throughout most of the Mesozoic era. These sedimentary and volcanic rocks crop out in two parallel bands today. Those on the west crop out as far south as southern Baranof Island, and those on the east crop out for the full length of southeastern Alaska. The source of these rocks is not positively known, but probably they were derived from the upraised Paleozoic sedimentary and volcanic rocks. Conceivably the volcanoes that contributed so heavily to the Mesozoic rock successions may have formed at the position now occupied by the large dioritic intrusive bodies. This volcanic activity probably was the forerunner of the later igneous activity which gave rise to the Coast Range batholith. Undoubtedly most of the folding and faulting seen in the area today is related to this period of igneous activity.

The rocks of Mesozoic age over a large part of the northern end of southeastern Alaska have been extensively recrystallized, and the extent of recrystallization at first glance seems to be far in excess of what would be expected from normal metamorphism of the bedded rocks in contact with diorite. The Mesozoic rock succession is many miles thick, which indicates that the lowest rocks were buried to great depths. These depths were, in fact, probably great enough to melt the sedimentary rocks. Much of the regional metamorphism found on Chichagof Island and on the west side of the Glacier Bay area may be the result of deep burial.

The igneous rock that makes up the Coast Range batholith is dioritic or granodioritic in composition. This igneous rock shows many evidences of having, in large part, formed from older rock by fusion, replacement, and recrystallization: thus one of the conclusions so far reached in the study of the northern end of southeastern Alaska has been that much of the so-called diorite may have been formed by such means (Rossman, 1959; Seitz, 1959).

After the diorite became crystalline, it was cut by major faults. The trace of one of these faults is still visible in the Lisianski Inlet and Peril Straits trough. These large faults were later the locus for small quartz diorite intrusive bodies whose magma may either be a late segregation of the earlier dioritic magma or the product of fusion and segregation of older rock.

Still later the Mesozoic racks were intruded by a gabbroic magma. The resulting masses crop out along a straight line extending from northern Chichagof Island northwestward to Mount Fairweather. Quartz dioritic magma, probably related to the gabbroic magma, was

intruded into the rock in the same general area at a slightly later time. The last igneous activity known is at the Mount Edgecumbe volcano, near Sitka on Baranof Island.

There are no rocks of Tertiary age within the mapped area and this part of the geologic record is therefore missing, but farther northwest along the continental shelf of the Gulf of Alaska a Tertiary rock succession, aggregating more than 40,000 feet in thickness, was deposited unconformably on the Mesozoic rocks. The oldest of the Tertiary rocks were mainly continental sediments which consist of thick sedimentary sequences containing coal. These continental sedimentary rocks are overlain by marine sedimentary rocks. The sequence also contains some volcanic rocks. At places the Tertiary rocks contain unconformities which indicate that uplift and folding were going on during Tertiary time.

Obviously southeastern Alaska underwent extensive glaciation in Pleistocene time, which was instrumental in giving the land its present topography. The last major glacial advance presumably of Wisconsin age is known to have almost completely covered southeastern Alaska, and only mountains above 3,000 feet in altitude extended through the ice. Although the glaciation was extensive and the amount of the glacial erosion was undoubtedly great, it certainly can account for only a small part of the landforms present in the area. These landforms must have developed slowly through the several earlier glacial stages of the Pleistocene epoch.

One of the outstanding features of the Glacier Bay area is the rapid advance and retreat of the glaciers during several substages within the last few thousand years. The intervals between the glacial advances were long enough for forests to become established before being destroyed by the next glacial advance. These forests have been covered by glacial deposits and in places are still preserved. Radiocarbon age determination of samples of wood from these ancient forests indicates that at least three forests existed. The date of their killing undoubtedly coincides with the advances of the ice. The oldest advance took place about 7,000 years ago; the next at 4,000 years; and the last, less than 500 years ago (Seitz, 1959). The last advance apparently was the most extensive; the glacier front reached as far south as the entrance to Glacier Bay, where it left a huge semicircular terminal moraine. A correlative advance appears to have taken place on the west coast, where a huge terminal moraine now encircles Lituya Bay; other large terminal moraines lie in the area between Lituya Bay and Icy Point. Figure 18, which was compiled largely from features visible on aerial photographs, shows in a general way the maximum advance of the glacier during the last glacial substage.

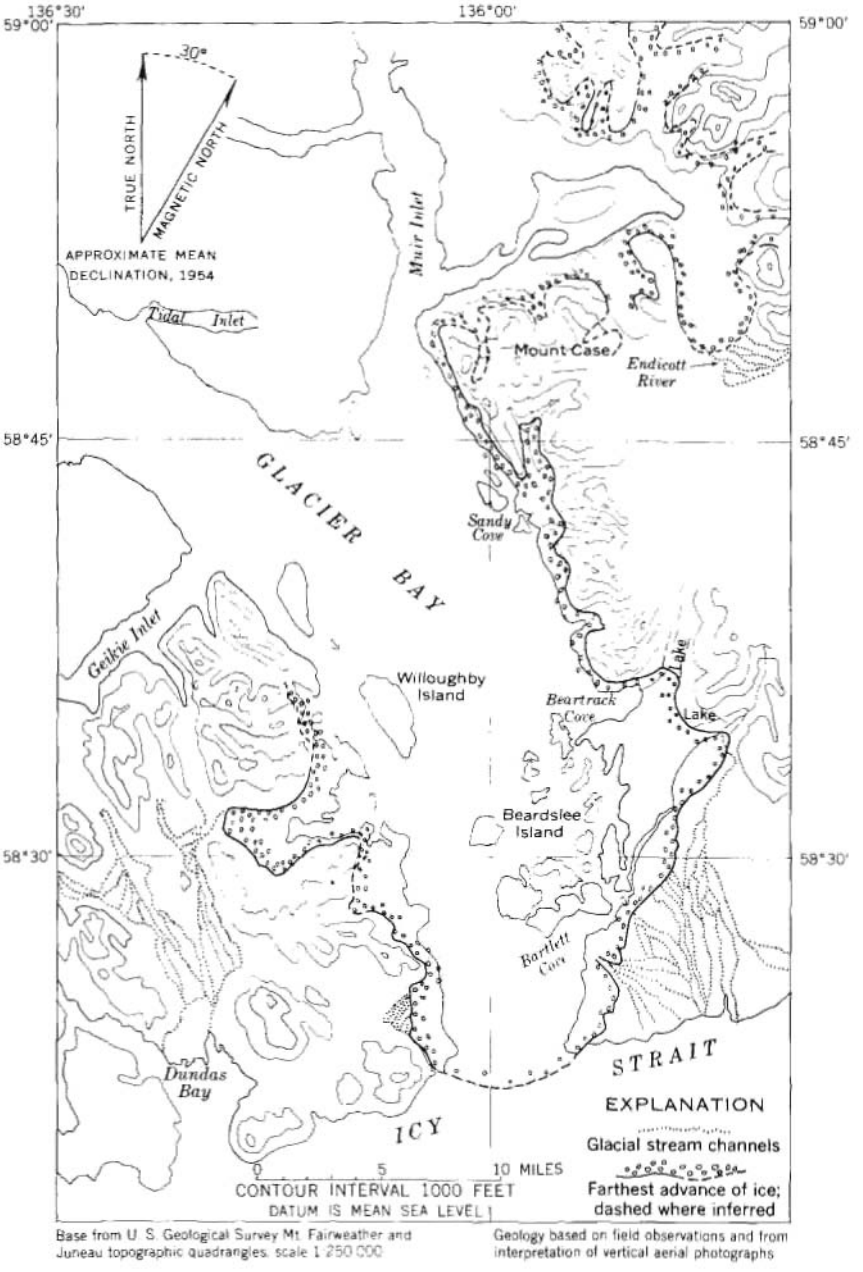


FIGURE 18.—Sketch map showing the farthest advance of ice in the last glacial cycle.

A well-developed marine terrace lies along the west coast of southeastern Alaska. Discussions and descriptions concerning the terrace have been given by earlier authors and need not be repeated here (Buddington, 1923; Reed and Coats, 1941). It probably formed during Pleistocene time and has been locally glaciated. This terrace at present stands only a few tens of feet to several hundred feet above sea level, but superimposed on it and in the higher mountains behind it are other marine terraces. One of the best developed of these is exposed in the west side of the coastal mountains 8 miles northwest of Lituya Bay. Today this terrace stands at an altitude of 1,600 feet.

There are many other indications of change of sea level found in southeastern Alaska; for example, marine sediments that were deposited after the last glaciation crop out at altitudes of as much as 600 feet (Twenhofel, 1952). Thus, it is certain that the relation of the height of the land to the sea has changed markedly within the last few thousand years.

MINERAL DEPOSITS

Only a small amount of ore has been mined in the mapped area. A small silver deposit was discovered on the west side of Willoughby Island in the early 1900's, but it has been mined out. Reed visited this deposit in 1936 and wrote a short report on it (Reed, 1938, p. 70–72).

A silver-bearing vein, reported to have been very rich, crops out at sea level on the west shore of Rendu Inlet about 3 miles north of its entrance. The deposit is reported to be covered by two claims patented in about 1892 and to belong to the Presbyterian Home for Elders in Seattle (Buddington, written communication). Reed (1938, p. 57–58) searched for the deposit, but he was unable to find it.

The property was examined during the course of the geologic mapping. The deposit is in a quartzitic phase of the rock mapped as diorite and is exposed for several hundred feet in a steeply dipping westward-trending vein. The ore zone is exposed over a vertical distance of about 100 feet. A tunnel was driven on the vein at an altitude of about 30 feet, but the entrance was caved when examined by the writer in 1951; consequently, all the observations and conclusions that are presented here are from surface outcrops. The vein itself crops out for only a few feet above the tunnel entrance. The ore zone consists of a small quartz vein emplaced along a local fault. The country rock is extensively altered for several feet on each side of the fault. The alteration appears identical to that of several other altered zones in the immediate vicinity, and all these zones appear to be genetically related. If this conclusion is correct, then any of the altered zones might be regarded as potential seats for ore deposition and would merit prospecting. A specimen of ore found at the prop-

erty contained some wire silver and considerable tetrahedrite. The ore minerals were concentrated along small fractures in the quartz and probably were emplaced after most of the quartz was deposited.

A molybdenite-bearing deposit crops out on "The Nunatak" on the east side of Muir Inlet. The deposit was studied by W. S. Twenhofel (1946). The present writer examined the deposits in only a cursory way and can add little more information. The lower part of "The Nunatak" is covered by glacially derived gravel that is being actively removed by the natural processes of erosion, and here steep-sided gullies are rapidly becoming so deeply entrenched that new outcrops are being formed along their bottoms. One such gully has exposed rock on the northeast side of "The Nunatak" that may not have been exposed at the time Twenhofel examined the area. The rock at this outcrop is mineralized and contains large masses of quartz. The exposures are too poor to indicate much about the rock, or whether an ore deposit is present. A grab sample, which was as representative as possible, showed by spectrographic analysis that it contained 0.04 ounce of gold and 7.07 ounces of silver to the ton. The rock also contains some visible molybdenite. From the general aspect of the outcrop it is inferred that the mineralized area is considerably larger than the outcrop. Conceivably a more highly mineralized zone lies in this area than is exposed elsewhere on "The Nunatak."

A copper deposit crops out at an altitude of about 1,200 feet on the side of Observation Mountain, which stands about 1 mile west of Rush Point in the B–1 quadrangle. In 1906 this deposit, known as the Alaska Chief property, was examined by the Wrights, who reported that the workings are at the contact of a dioritic mass and calcareous sedimentary rock (Wright, C. W., and Wright, F. E., 1937). The deposit was not examined by the writer, but Reed (1938) reports that "mineralization consists of replacement of marble and contact rocks and sulfides."

A small amount of molybdenite was found on Triangle Island in Queen Inlet by Frank Schotter, of Hoonah, who reported that only a few hundred pounds of molybdenite was present, and that he had removed most of it in 1 day. A few molybdenite-bearing quartz veins crop out along the western shore and in the lower western part of the mountains on Gilbert Island. The largest of these veins is less than 1 foot thick, and the amount of molybdenite in it is small. These veins probably have no commercial value as a source for molybdenite.

Molybdenite was found in one small outcrop in the north-central part of the Bruce Hills at the north edge of the mapped area. The molybdenite is in fractures in an intrusive gray diorite which is intermixed with sedimentary rock. The molybdenite forms in crystals as

much as half an inch in diameter, which are tough and resistant to abrasion. The molybdenite-bearing deposit is only a few feet in diameter. Exposures are excellent on the hillside where the molybdenite crops out, but a rapid search in the immediate vicinity failed to show any more molybdenite mineralization. Probably no large ore body is present near this mineralized area, but only a small part of the Bruce Hills was examined and possibly other mineralized zones lie in them. They have probably not been prospected to any great extent, because they have been exposed above the ice only for a few tens of years and during this period there has been little prospecting activity in the area.

Gold has been found in the quartz veins on the west side of the mountain standing between Dundas Bay and Brady Glacier. The number of veins there is small, however, and few are more than a few inches thick. Quartz veins also crop out on the south and west side of Gilbert Island, and some of them contain tetrahedrite, galena, sphalerite, and pyrite. By crushing and panning samples from these veins a small amount of free gold was recovered. The largest vein that was found crops out on the shore north of Blue Mouse Cove on the south end of Gilbert Island. This vein, which is more than 1 foot thick, contains tetrahedrite, pyrite, and some gold; it is also reported to contain some silver.

Only one group of quartz veins was found in the entire land mass between Queen Inlet and the east edge of the mapped area. Altogether the group contains 6 to 10 veins, which range in thickness from less than 1 inch to slightly more than 1 foot. The veins crop out at an altitude of 3,000 feet on the west side of Pyramid Peak. They contain pyrite, but no other metallic mineral was detected.

Several quartz veins, all less than 1 inch thick, were found on the north shore of the largest island in the extreme southeast corner of the D–1 quadrangle. These veins contain abundant galena, sphalerite, and locally, pyrite and calcite; they may well contain gold and silver, but probably are too small to be of any economic importance. Other mineralized areas have been found in this same general area. Silver-bearing quartz veins crop out near Sandy Cove near the contact of a small granitic stock (Reed, 1938, p. 65–69).

Placer gold has been mined from the glacially derived gravels, south of Wood Lake in the C–2 quadrangle and in the upper part of the Dundas River drainage basin. Placer mining of the outwash in front of Brady Glacier was carried on for some time in the early part of the century.[1] The gold in this last-mentioned area is very

[1] Personal communications from Mr. Frank Schotter, of Hoonah; Mr. James Barnett, of Juneau; and Mr. Clell Hodson, of Elfin Cove and Pelican.

fine-grained and can scarcely be recognized with certainty even with a hand lens. Mining activity apparently was carried on for only a short time, and the amount of gold recovered was probably small.

A mass of sphalerite and magnetite lies in the limestone on North Marble Island, and other mineralized zones crop out on Francis and Willoughby Islands.

The deposits on Francis and North Marble Islands are associated with dark-colored dike rocks, and those near Sandy Cove are near bodies of igneous rock. The close obvious relation between the igneous rocks and mineral deposits is unique within the area mapped, and the writer is inclined to believe that the deposits represent a separate province of mineralization, not directly related to the other mineralization found farther north.

Paligorskite, an asbestoslike amphibole, crops out in two deposits on Lemesurier Island (pl. 1) in the southern part of the B–1 quadrangle. Robert Thorne, of the U.S. Bureau of Mines, investigated these deposits and published a short report concerning them (Fisher and others, 1945). One deposit lies on the bank of the small stream about 600 feet from the beach near Jacks Cove on the south side of Lemesurier Island. The other deposit crops out at an altitude of about 1,100 feet at the top edge of a near-cliff, 1½ miles by trail from Willoughby Cove. The deposits will be referred to in this report as the lower and upper deposits, respectively.

Both deposits are formed in and on the Willoughby limestone, and both lie at approximately the same stratigraphic position; however, they probably are not genetically dependent on any unique composition of any particular bed. Apparently the deposits are close to the uppermost limestone bed of the Willoughby limestone. At the time of the writer's visit in 1951, the lower deposit covered about 40 or 50 square feet. A small solution cavity several feet in diameter and about 8 feet long extends into a small cliff near the main lower prospect, and this cavity contained a small amount of spongy paligorskite. Mr. Joseph Ibach, the owner, reports that originally the cavity was nearly filled with this material, but that he had removed most of it.

The uppermost beds exposed at the lower deposit consist of thin-bedded dark-colored sedimentary rock which possibly marks the contact between the Willoughby limestone and an overlying unit. Igneous dike rock also crops out at the deposit. Paligorskite is in small near-surface fractures in bedrock and on bedrock beneath a cover of soil. Both the dike and the adjacent limestone contain calcite veinlets.

The limestone at the upper deposit strikes N. 30° E. and dips 30° SE. The rock is a fairly massive white limestone and, like the rock at the lower deposit, is cut by calcite veinlets. The paligorskite here is on top of the limestone beneath the soil, but it is not certain whether the mineral actually formed at this position or was carried to it by natural processes of transport. The inaccessible nature of the terrain renders it difficult and somewhat hazardous to work near this deposit; this condition, coupled with the poor exposure, and the fact that most of the paligorskite has been removed, made it impossible to do more than examine the deposit in a rather sketchy fashion.

The method of formation of the paligorskite deposits is still not completely understood. Probably they formed both at the surface and in preexisting openings in bedrock; locally, the bedrock has been replaced or altered to a mineral with some of the physical characteristics of paligorskite. The fact that both deposits are associated with calcite veinlets leads one to believe that there is some genetic connection between the calcite and the paligorskite. Possibly the deposits formed from ascending waters either at a temperature no higher than that of normal near-surface groundwater or at only a moderately higher temperature. If this is in effect the method of formation of these deposits, then one cannot expect to find appreciable amounts in bedrock except locally in solution cavities and open fractures.

Hydrothermally altered rock is widespread along fault zones in the Glacier Bay area. Most of these altered zones contain no quartz, but in a few that do, the quartz contains some gold. Generally the altered rock weathers to a rust-red color owing to the oxidation of iron carbonate with which the altered zones are nearly everywhere associated. A few of these altered zones have been checked for radioactive minerals, and some from the area near Sandy Cove showed that they contain between 0.001 and 0.003 percent U_3O_8. Thousands of these altered zones exist in the area, and probably only a small percent have been examined by any person. The writer is of the opinion that these altered zones merit some prospecting, mainly as a source of gold and silver, but also for other elements, such as uranium.

A zone of hydrothermally altered rock more than a thousand feet in diameter lies on the west side of White Cap Mountain near Dundas Bay. The rock within the zone has been profoundly altered and now consists of talc, quartz, and pyrite. No valuable ore minerals have been detected, but inasmuch as the zone is large and highly altered it is probably well worth prospecting.

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