Geology of Geikie Inlet Area Glacier Bay, Alaska

By JAMES F. SEITZ

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By James F. Seitz

ABSTRACT

The Geikie Inlet area is in the Glacier Bay region of southeastern Alaska, about 100 miles northwest of the city of Juneau. The area is mountainous with relief of slightly more than 5,000 feet, and the coastline is deeply indented by fiords and inlets. Most of the western half of the area is covered by glaciers.

Beds of metamorphosed marine sedimentary and volcanic rock constitute about one-third of the bedrock exposed in the area, and total 23,000 feet and possibly more of stratigraphic thickness. Included in this is one sequence 8,000 feet thick composed mostly of limestone beds with some intercalated beds of shale and volcanic rock in the upper part. The lower part is of relatively pure, gray limestone and contains fossils that have been tentatively identified as belonging somewhere in a Silurian to Permian age range. The bedded rocks also include a sequence, possibly 15,000 feet thick, composed largely of metamorphosed shale and graywacke beds, but containing large amounts of interbedded limestone and volcanic rock. The shale, which includes calcareous and dolomitic shale, and the graywacke have been metamorphosed to hornfels and granulite and have predominantly granoblastic textures. The most common minerals in these metamorphosed rocks are hornblende and oligoclase or andesine, with the addition of diopside where the composition of the original sediment favored its formation.

Two other bedded rock units, having a thickness of a few hundred feet at the most, are exposed at only two localities; they are a bed of conglomerate and a sequence of argillite and graywacke. The rock in both units is relatively unmetamorphosed, which indicates that the two units probably are unrelated to the other bedded sequences in the area.

Limestone of the Willoughby limestone formation (probably of Late Silurian age) forms one isolated outcrop within the area, but its relationship to other bedded rock in the area has not been determined. In adjacent areas the Willoughby limestone forms large and conspicuous outcrops that reveal a stratigraphic thickness of more than 5,000 feet.

Bodies of diorite ranging from 25 feet to 12 miles in length are distributed through the area; altogether they total about one half of the bedrock exposed. The largest of these, in the western part of the area, is a fairly well defined elongate northward-trending body. The rest of the diorite is distributed in many smaller and less well defined masses through parts of the eastern third of the area.

A notable characteristic of the diorite is the heterogeneity of its appearance. This heterogeneity is due to the pronounced irregularity in texture, variety and abundance of inclusions, and the scattered migmatitic zones in the rock. The irregularity of texture is due to variations in the size of constituent mineral grains and the irregular outlines of the larger crystals, which are typically porphyroblastic. This textural irregularity is most pronounced near contacts between diorite and bedded rock where broad irregular zones of gradational types of rock have formed. In many of these places migmatitic rock has formed; the migmatitic rock, which is composed largely of porphyroblastic plagioclase and hornblende, is termed hornblende-plagioclase rock in this report.

Another characteristic of the diorite is planar fabric that is reflected by gneissic banding and oriented inclusions of both bedded rock and fine-grained diorite. The orientation of this fabric follows a generally northward strike and is parallel to the prevailing strike of the bedded rocks in the area. This parallelism is maintained across contacts between diorite and bedded rock regardless of whether the contact is parallel to the bedding or at right angles to it.

These gross features of the diorite, and other smaller scale ones indicate that the diorite is of metamorphic rather than igneous origin.

Three stocks of granodiorite, ranging from half a square mile to 10 square miles in area, have been intruded into the diorite and bedded rocks in this area. These stocks may probably be correlated with similar bodies that were intruded during the Mesozoic era in other parts of southeastern Alaska.

Within the mapped area the structural trends in the diorite and the bedded rock generally follow a strike ranging from north to northeast with dips ranging from 60° W. to 60° E. This trend constitutes a divergence from the regional northwestward trend that prevails throughout most of southeastern Alaska, and may possibly be an indication that the Glacier Bay area lies near the margin of the structural province that extends to the southeast. Most faults in the area are parallel to the regional trend and strike northwestward; Shag Cove, Tyndall Cove, and Favorite Fiord are conspicuous examples of the expressions of such faults. Most of the other faults in the area are at right angles to this northwesterly trend; among these are the faults that probably determine the position and trend of Geikie Inlet and the gorge of Abyss Lake.

The area is now partly covered by valley glaciers, and within the past 8,000 years has been largely covered several times with ice sheets originating to the north and west. After each retreat of an ice sheet, forests of hemlock and spruce flourished only to be overwhelmed and buried by the succeeding ice sheet. Dating of these buried trees by radiocarbon methods has determined the times of each of the ice advances. The most recent advance took place within the last 500 years and the retreat began about 150 years ago. The valley glaciers within the area are all retreating rapidly at present.

No mineral deposits of economic value were found in the area although strong magnetic anomalies in one place suggest the presence of buried magnetite.

INTRODUCTION

The area described in this report is about 80 miles west and 25 miles north of the city of Juneau, Alaska (fig. 10). It includes 340 square miles on the west side of Glacier Bay and lies on the north, west, and south sides of Geikie Inlet (fig. 11). It extends from Hugh Miller Inlet on the north to Serrated Peak on the south, and from

FIGURE 10.—Index map of Alaska showing location of Glacier Bay.

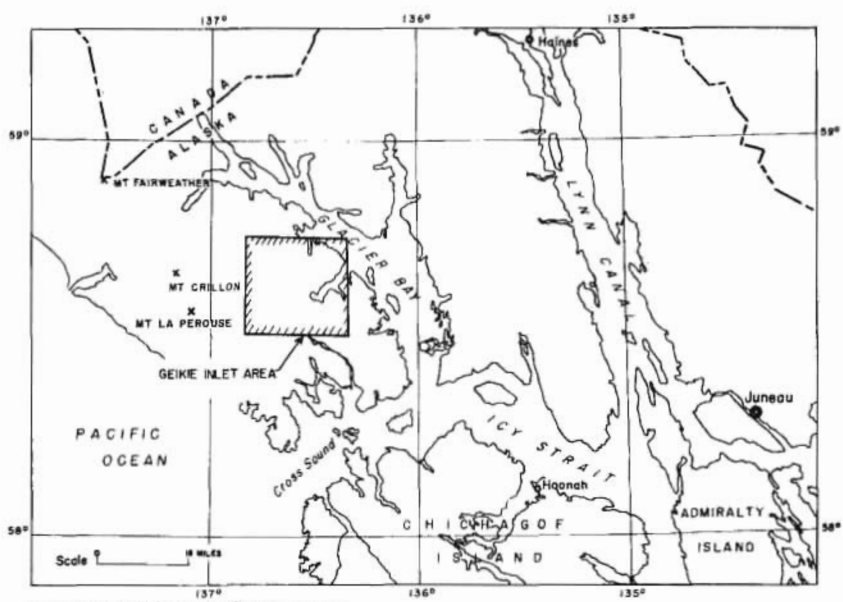

FIGURE 11.—Index map showing Glacier Bay region and Geikie Inlet area.

Tlingit Peak on the east to the central part of Brady Glacier on the west. The boundaries are 136° 20′ and 136° 50′ west longitude, and 58° 30′ and 58° 45′ north latitude with the exception of one small spur that projects north of this latitude. It comprises Mount Fairweather quadrangle C–2 and the east half of Mount Fairweather quadrangle C–3.

PREVIOUS INVESTIGATIONS

The first investigation of bedrock geology in the Glacier Bay region was made in 1890 by H. F. Reid (1896) and H. P. Cushing (1895). This was a reconnaissance study of areas near the shores of the bay and its inlets. One of the major contributions of this study was the determination of the age of a conspicuous and widely distributed Upper Silurian limestone unit.

A second and more intensive geologic mapping program of the Glacier Bay region was started in 1906 by F. E. Wright and C. W. Wright for the U. S. Geological Survey (written communication). The fieldwork was completed in 1931 after a 25-year suspension of the project. Their report deals principally with glaciation and glacial history, but includes a section on the bedrock of this area in a description of the general geology of the region from Taku Inlet to Lituya Bay.

In 1919 J. B. Mertie, Jr. of the U. S. Geological Survey spent several days in the Geikie Inlet and Hugh Miller Inlet areas studying the outcrops along the shores (field notes in the files of the U. S. Geological Survey).

In 1941 J. C. Reed of the U. S. Geological Survey spent two days in the area at the head of Geikie Inlet in the course of investigating mineralization in the region (field notes in the files of the Geological Survey).

No further recorded investigation of this area was made prior to the present study.

PRESENT INVESTIGATION

The present investigation is part of a mapping program planned for part of the Glacier Bay region. The fieldwork was done from June to September in 1950 and during the last three weeks of August in 1951. The author was assisted in 1950 by Dwight Crowder and Kermit Bengston, and in 1951 by Clifford Hopson.

Aerial photographs of 1:20,000 and 1:40,000 scale were used for field mapping as no accurate map of the area existed at the time the fieldwork was done. A planimetric map was compiled subsequently by the author from aerial photographs, with control data furnished by the Topographic Division of the U. S. Geological Survey, and was used as a base map in the office. In 1954 a preliminary copy of a topographic map of Mount Fairweather C–2 quadrangle was supplied by the Topographic Division and this, combined with the Mount Fairweather C–3 quadrangle portion of the planimetric map, provided the base map for this report.

A cruiser-type boat provided living quarters for the party in the field, and transportation to the nearest town for supplies and mail. A small fast outboard motorboat was used for daily commuting to the work areas. In the interior areas the party traveled on foot, and equipment was transported by pack and sled. Expendable supplies such as food and fuel were transported by plane and dropped from low altitudes onto soft snow. In the western areas five different camps were established for work on a continuous circuit route via Geikie, Brady, Aurora, Hugh Miller, and Charpentier Glaciers.

ACKNOWLEDGMENTS

In the preparation of this report, Prof. Peter Misch of the University of Washington generously reviewed the work as it progressed, and offered many helpful suggestions.

The three assistants who helped in the fieldwork, Dwight Crowder and Kermit Bengston in 1950, and Clifford Hopson in 1951, not only furnished much technical help but also, because of their outstanding mountaineering abilities, contributed greatly to the safety of the party and to the speed with which the work was accomplished.

GEOGRAPHY

PHYSIOGRAPHY

The Geikie Inlet area is bordered on the northeast by Glacier Bay and is deeply indented by two fiords, or inlets, that extend from the bay into the area. The larger of these fiords is Geikie Inlet, ranging in width from 1 to 1½ miles and nearly 9 miles long. This relatively straight inlet extends southwestward from Glacier Bay into the central part of the area and its coastline is indented on the southeast side by two smaller inlets, Tyndall Cove and Shag Cove. As its trend is normal to the direction of flow of the major ice sheets that filled all of Glacier Bay, it has not been carved into a steep-walled fiord as many of the inlets have.

The other fiord in the area is Favorite Fiord. It extends southeastward into the area from Charpentier Inlet and forms a canyon with walls 1,500 feet high on either side, an average width of a quarter mile throughout its 4-mile length, and a maximum depth of about 500 feet. It would connect directly with the water of Geikie Inlet, isolating the Mount Favorite–Hugh Miller Mountain area as an island, were it not blocked off at the southeast end by a delta from a side valley that has filled about a mile of the channel of the fiord.

The area is predominantly rugged with an overall relief of 5,000 feet and a local relief on some cliff faces of as much as 2,700 feet. Sharp-spired peaks, high, narrow ridges, and sheer-walled valleys that have been produced by alpine glaciation are prevalent. Most of the larger valleys in the central and western parts of the area are still occupied by glaciers that descend nearly to sea level, but all these glaciers are receding rapidly and if the present climatic conditions continue their termini will eventually be high up in the mountains. The west side of the area includes the margin of a vast piedmont glacier called Brady Glacier, which has its source in the higher mountains of the Mount Fairweather Range to the west. Unlike the valley glaciers to the east, there has been little fluctuation in height of Brady Glacier in the past several hundred years and there will probably be little change in the near future.

CLIMATE

Weather records are maintained at the Cape Spencer lighthouse, 20 miles south of Mount Fairweather C–2 quadrangle. Although in this region the weather varies locally and is affected by topography and by proximity to the ocean and to large glaciers, the weather records for 14 and 18 years for precipitation and temperature respectively kept at this station do give a general idea of the weather that prevails in the Geikie Inlet area. These records show that the average annual precipitation is 111.63 inches and the average annual temperature is 42.2°F. The average monthly precipitation for the summer months in the area is as follows: June, 5.74 inches; July, 7.63 inches; August, 9.1 inches; and September, 15.4 inches. The average temperature for these months is: June, 49.1°F; July, 52.3°F; August, 52.6°F; and September, 50.3°F.

The following table of weather records as noted by the author during the summers of 1950 and 1951 gives the percentage of days in each month that were predominantly clear and sunny and the percentage of days during which it rained fairly hard for more than half a day. These records illustrate the difficulty of predicting how much good weather is going to be available for fieldwork in a summer and during which part of the summer it will occur.

Record of clear and rainy days, in percent, for the summers of 1950 and 1951

	Clear		Rainy	
	1950	1951	1950	1951
June	53	33	20	40
July	22	51	52	0
August	61	29	26	32
Average	48	38	32	24

The record from 1951 shows that the number of rainy days was greatly exceeded by the number of cloudy days. However, as the clouds usually lie only a few hundred feet above sea level and envelop everything above this in dense fog, fieldwork is hampered almost as much by cloudy weather as it is by cloudy and rainy weather. Another climatic factor affecting fieldwork in the area is the percentage of time that the ground is covered by snow. On the first of June the entire area from Geikie Inlet north is normally still covered by a deep thickness of snow from the high-tide line to the summits of the peaks, and by the end of August fresh snow again covers the slopes above 4,000 feet altitude. The greatest area of bare ground is exposed early in August.

VEGETATION

Hemlock and spruce trees are limited to a few localities in the southern part of the area where they escaped destruction by the advance of the last ice sheet. Prior to the advance of this ice sheet they were widely distributed and probably covered all slopes up to an altitude of about 1,500 feet. The present climate is favorable to the growth of spruce and hemlock trees and eventually the area will be covered by forests of them. At present parts of the area below 2,000 feet altitude which have been free of glaciers for at least 25 years are densely covered by a transitional stand of cottonwood trees, willow trees, alder, and brush. Salmonberry bushes and devilsclub are common south of Geikie Inlet but have not yet become established north of it.

ANIMALS

Wolves, black bears, mountain goats, land otters, marmots, and smaller rodents live in the area. The glacier bear, a variant of the black bear with color markings resembling those of a Siamese cat, ranges into the southern part of the area but is not abundant. Fowl, both migratory and nonmigratory, are abundant and include ptarmigan, bald eagle, golden eagle, Canadian goose, several species of ducks, puffin, coot, cormorant, and sea gull. The geese and some of the ducks, especially the scoters, form flocks of thousands and at times cover acres of water.

Sea life is abundant in the area with the ever-curious hair seal being the most frequently seen animal of this group. Although efforts are being made to exterminate them, they are still present in all parts of the bay. Humpback whales are also seen, commonly in small groups, and according to biologists the inlets of Glacier Bay are a breeding ground for them. The humpback whale is not at all timid and sometimes can be approached with a small boat within a few feet. Killer whales, the predators of the humpback whales, are also seen occasionally in the bay where their high dorsal fins mark them conspicuously, but they tend to be shy and are difficult to approach for close observation. Violent battles between a humpback whale and a pack of killer whales sometimes take place, accompanied by tremendous splashing and noise that can be heard for 5 miles.

The salmon is the most abundant fish in the area, and also the most important commercially. Many of the small clear streams in the area are used by the salmon for spawning in spite of the fact that these streams have become accessible to them only recently after withdrawal of the last ice sheet. Enough salmon spawn in the new streams to populate them quickly. This is contrary to a long-standing tradition that a salmon always returns to the stream in which it was spawned. Other sea life in the area are halibut, sculpin, cod, shrimp in several sizes, and crabs including the king, Dungeness, and tanner. Many other species of marine life are undoubtedly present but were not identified by the author.

CULTURE

The Geikie Inlet area is uninhabited at present and no evidence of earlier occupation was found. However, if people lived in the area prior to the advance of the last ice sheet, all evidence of this would have been obliterated or buried by the advancing ice. An item of evidence favoring the possibility of an earlier occupation is furnished by a Tlingit Indian legend which relates the story of an evacuation of a village in the Glacier Bay area because of the advance of a large ice sheet (Houston, 1952, oral communication). From the glacial evidence available this could have happened as recently as 300 years ago.

TRANSPORTATION AND ACCESSIBILITY

The channels and inlets provide excellent accessibility both by boat and by seaplane. A small plane can reach the area from Juneau in an hour, and a boat capable of 10 knots speed can reach it in 12 to 18 hours depending upon the tidal currents. Several good anchorages are to be found in Geikie Inlet, the best protected one being a tidal lagoon formed from a kettlehole on the delta between Geikie Inlet and Favorite Fiord. It is well sheltered and large but it can be entered or left only on a tide higher than 17 feet. However, a boat could be left here unattended for weeks with relative safety. An excellent anchorage for one boat is provided by a small, narrow cove half a mile west of the tidal lake on the northwest shore of Geikie Inlet. This cove was used during the entire field season in 1950 by our party and furnished safe protection even during absences of 2 weeks duration. The waters of Geikie Inlet are rarely rough so that adequate moorage can be found at many other places along its shores and side inlets provided the boat is checked daily. Hugh Miller Inlet also provides a number of fairly sheltered anchorages although the presence of several uncharted reefs necessitates caution in navigating this body of water.

Parts of the area are accessible by a plane equipped with a combination ski-wheel landing gear. Landings could be made with this on Aurora and Brady Glaciers at any time of the year and on Charpentier Glacier and possibly Geikie Glacier during the winter and spring.

The practical means of travel within the area is by foot. Equipment and supplies may be transported by packing and sledding, and by dropping, either free fall or with parachutes, from a plane.

REGIONAL GEOLOGIC SETTING

The area described in this report lies within the broad mountain belt that encompasses all of southeastern Alaska. The bedrock in this belt is largely of sedimentary and igneous rocks of Paleozoic and Mesozoic age and includes a small amount of rocks of Tertiary age. The regional folds and faults have northwestward-trending axes. This uniformity of trend is reflected in the alinement of the mountain ridges and of the long, straight channels, inlets, and valleys.

The rock of the area includes a sequence of limestone, granulite, and hornfels beds derived from marine sedimentary rocks. An estimate has been made from a few poorly preserved fossils that the age represented is post-Silurian and pre-Triassic. One limestone body that forms an isolated outcrop in the area can be correlated with the Willoughby limestone, which crops out in adjacent parts of the region and which has been tentatively determined to be of Late Silurian age.

As the Willoughby limestone is the only rock unit in the area with an age that is moderately well established, a description of outcrops of this limestone that lie a few miles east of Mount Fairweather C–2 quadrangle and in which the diagnostic fossils were found is pertinent to this report. The limestone makes up the entire bedrock of Francis, Drake, and Willoughby Islands that all lie east of Geikie Inlet and it was here that H. P. Cushing in 1890 first collected fossils. From these fossils Charles Schuchert determined the age of the limestone to be Late Silurian.

He considered a large species of the genus *Leperditia* to be diagnostic (Brooks, 1902). In 1906 C. W. Wright and F. E. Wright collected fossils from the same locality and E. M. Kindle identified them as including the following: *Limoptera* sp., *Paracyclas* sp., *Pleurotomaria* n. sp., *Murchisonia* sp., and *Megalomus* sp. (Wright,

F. E., and C. W., 1937). Later Edwin Kirk described two new genera from this same locality, a gastropod which he named *Bathmopterus liratus* (Kirk, 1928), and a pelecypod, previously identified as *Megalomus*, which he named *Pycnodesma giganteum* (Kirk, 1927a) and later changed to *Pycinodesma giganteum* (Kirk, 1928). In 1949 D. L. Rossman and the author collected fossils from this locality and Edwin Kirk identified them as *Hormotoma* sp., *Coelocoulas* sp., *Holopea* sp., *Eccyliomphalus*, and *Pycinodesma giganteum*. An abundance of the large and thick-walled *Pycinodesma giganteum* in some zones is a conspicuous characteristic of this limestone of Late Silurian age.

Immediately east of the mapped area, on the east side of Shag Cove, the Willoughby limestone makes up the entire bedrock of Marble Mountain. Although much of the limestone here is massive, traces of thick, westward-dipping beds on the northeast slopes of the mountain indicate that the stratigraphic thickness may be more than 5,000 feet.

GEOLOGY

GENERAL DESCRIPTION

The description of the geology should be prefaced by brief definitions of several rock names used in this report to avoid possible misinterpretation. Of the names used in a restricted sense, the term "granulite" is applied to recrystallized rocks that have a granulose texture and lack schistose or gneissose structure. The grain size ranges from about 0.5 to 2 millimeters. The term "hornfels" is applied to recrystallized rock also lacking schistose or gneissose structure but with a finer texture than granulite. Both of these types of rock occur mostly in well-bedded sequences. The term diorite is used for a crystalline rock composed largely of oligoclase or andesine, hornblende, and quartz. The term "hornblende-plagioclase rock" is applied to rock composed largely of hornblende and plagioclase that has a texture coarser than the granulite and more irregular than the diorite.

Bedded rocks constitute about a third of the exposed bedrock in this area and represent a stratigraphic thickness totaling more than 23,000 feet. The rocks include the Willoughby limestone formation; an argillite and graywacke sequence and an associated conglomerate unit; a sequence approximately 8,000 feet thick, of gray and tan thick- and thin-bedded limestone and interbedded hornfels; and a sequence of beds, possibly 15,000 feet thick, of granulite and hornfels with minor amounts of interbedded limestone and volcanic rock. The relationship of the Willoughby limestone to the other bedded rock in the area is not known as contacts between the one outcrop of this formation and adjacent beds are not exposed. The beds from which the granulite and hornfels of this area were derived are probably represented in the thick sequences of argillite, graywacke, and limestone exposed on the east and northeast sides of Glacier Bay, but at present not enough is known about these to warrant correlation.

Diorite makes up about half of the exposed bedrock and occurs principally in two large areas separated by a central, northward-trending belt of bedded rock. The diorite is composed principally of plagioclase (oligoclase to andesine), hornblende, and quartz, but the proportions of these and the amounts of the minor and accessory minerals vary considerably. Fabric ranges from nondirectional to prominent gneissic banding; texture, from uniform over large areas to highly variable and patchy within areas of less than a square foot; grain size, from medium to coarse; and color, from light to dark gray with patches of red on many weathered surfaces. One persistent feature of the quartz diorite is that contacts between it and adjacent rocks, where compositions are similar, are characteristically gradational.

Three stocks composed of granodiorite lie within the area. One about 10 square miles in area lies in the vicinity of Abyss Lake, another about 3 square miles in area forms much of Mount Bulky, and the third of about one-half of a square mile in area lies on the north side of Gullied Peak The granodiorite is highly felsic, monotonously uniform in composition, and devoid of a preferred fabric throughout all three stocks. The granodiorite stocks have intruded both the diorite and the bedded rock and probably are related to other similar bodies in southeastern Alaska that were emplaced during the Mesozoic era.

BEDDED ROCKS

WILLOUGHBY LIMESTONE

The Willoughby limestone of Late Silurian age forms a knoll 200 feet high and a mile long at the point of land on the northwest side of the entrance to Geikie Inlet. The lithogic character of this outcrop and its location indicate that it is part of the limestone unit that makes up Marble Mountain and Francis, Drake, and Willoughby Islands to the southeast. The limestone in this outcrop is massive with no trace of bedding so that the stratigraphic thickness exposed here cannot be estimated, but on Marble Mountain, 2 miles southeast of this outcrop, traces of bedding on both the east and west faces on the upper part of the mountain indicate a stratigraphic thickness of 5,000 feet, and possibly more. However, this estimate is tentative as no detailed study of the limestone on this mountain has been made. Both Marble Mountain and the limestone outcrop on the northwest side of Geikie Inlet are bordered on the southwest by valleys and a cove that are the physiographic expression of a continuous and major fault.

Most of this limestone is crystalline with a fine- to medium-grained texture but in places it is coarsely crystalline marble with individual calcite crystals averaging one-fourth inch across. The limestone is uniformly light gray except where bedding is revealed by darker gray bands. Most of it is massive and the beds that are exposed average several feet in thickness.

Other isolated masses of thick-bedded to massive gray limestone are exposed in the Geikie Inlet area and may belong to the Willoughby limestone but as they were not positively identified they will be grouped in this report with other limestone units of unknown age.

CONGLOMERATE

Conglomerate is exposed in two small outcrops, one on the north shore of Geikie Inlet, one-fourth mile southwest of the knoll of Willoughby limestone, and the other on the tip of land on the west side of the mouth of Shag Cove. This conglomerate is made up of pebbles and boulders of chert, limestone, argillite, and andesite. Individual boulders of limestone in it are as much as 3 feet in length. In other parts of southeastern Alaska, limestone of Late Silurian age contains intercalated lenses of conglomerate that, according to published description (Buddington and Chapin, 1929) closely resembles this conglomerate. This conglomerate therefore may be part of the Silurian sequence even though there is no evidence here of its relation to the nearby Willoughby limestone.

LIMESTONE SEQUENCE

A broad belt of limestone beds lies in the central part of the mapped area and extends northward from the north ridge of Blackthorn Peak to the east branch of Hugh Miller Glacier. The beds strike generally north and dip steeply eastward. The longest cross section through this belt is exposed along Goat Ridge where the total stratigraphic thickness exceeds 8,000 feet.

The westernmost 3,000 feet of the limestone sequence is composed of thick-bedded gray limestone with some beds of black limestone and several intercalated layers of hornfels and chlorite schist. This part of the sequence is exposed in section from the east margin of the north branch of Geikie Glacier to the first saddle east of the summit of Fossil Peak, and from the east margin of Hugh Miller Glacier to the first saddle east of the 4,160-foot peak that stands at the west end of the ridge. The limestone on the summit of Fossil Peak contains many poorly preserved specimens of a colony-type coral, and the limestone on the ridge northwest of the 4,160-foot peak contains crinoid stems, brachiopods, and specimens of the coral *Syringopora*. The age of the limestone has been tentatively determined as younger than Silurian and older than Triassic.

The easternmost 5,000 feet of this sequence is thin-bedded gray, black, tan, brown, and red limestone interbedded with minor amounts of hornfels. Shaly limestone, dolomitic limestone, pyrite-bearing limestone, carbonaceous limestone, and cherty limestone are common in this sequence. Differences in composition in adjacent beds have resulted in widespread differential weathering with the more resistant beds projecting above the surface of the less resistant beds. Where successive beds alternate in composition the result is a pronounced ridged pattern. Although the general trend of the limestone beds is uniform, locally the limestone is intensely deformed.

Extensive masses of dolomite crop out on the mountains bordering the west side of Hugh Miller Glacier and the upper part of the north branch of Geikie Glacier. They form bodies of irregular shape within a sequence of limestone and hornfels beds; their outcrops appear as white patches scattered at random over the limestone cliffs. The irregularity of borders and the transition from limestone to dolomite along the strike of the limestone beds suggest that the dolomite has formed by replacement of the limestone. If so, all traces of relict bedding have been obliterated in the process, as the dolomite is massive and structureless.

ARGILLITE AND GRAYWACKE SEQUENCE

The argillite and graywacke sequence is composed of argillite beds, 1 to 6 inches thick, and graywacke beds, 1 to 12 inches thick. In places the two are interbedded on an inch by inch basis and in other places the argillite alone forms zones as much as 100 feet thick. The sequence is best exposed on the island in the mouth of Shag Cove. Here a continuous section about 800 feet thick is exposed, with beds striking generally N. 40° W. and dipping roughly 60° NE., though minor folding causes some deviation from this altitude. Argillite beds predominate on the western part of the island and are interbedded with graywacke over the remainder of the island.

The argillite and graywacke sequence also is exposed on the west shore of Shag Cove and in a stream bed 1 mile upstream from the mouth of the easternmost creek entering Geikie Inlet on the northwest side (see pl. 6). The relation of these beds to other nearby bedrock is not known because contacts are not exposed.

The argillite is black, dense, and hard, and has a tendency to fracture smoothly along several planes, including the bedding plane. The rock in thin section reveals many discontinuous carbonaceous bands spaced on the order of 0.1 millimeter. These bands form a discontinuous, flaserlike structure instead of a layered structure. Between the bands the argillite is composed of a fine mosaic of sericite and quartz. The chemical composition of this rock is as follows: SiO_2, 69.9 percent; Al_2O_3, 11.6 percent; Fe_2O_3, 4.9 percent; MgO, 5.0 percent; CaO, 2.6 percent; Na_2O, 0.82 percent; K_2O, 2.4 percent.

The graywacke is greenish gray and composed of clastic grains, ranging from 1 to 5 millimeters in diameter, set in a matrix of biotite, chlorite, quartz, and calcite. In places the clastic grains are derived largely from quartz and plagioclase crystals and in other places they are of plagioclase arranged in a fine mosaic pattern. The contemporaneous biotite and chlorite suggest that metamorphism took place in the cooler mesozonal range.

METAMORPHOSED SHALE AND GRAYWACKE SEQUENCE

OCCURRENCE AND DISTRIBUTION

Beds composed originally of graywacke and calcareous and dolomitic shale with intercalated beds of arkose, limestone, and lava, all now highly metamorphosed, make up a continuous sequence that totals more than 13,000 feet in stratigraphic thickness. They form an irregular and discontinuous belt that extends from Threesome Mountain on the south through Gullied Peak on the north. The greatest exposed width of this sequence is in the area between Red Bed Peak and Maynard Glacier where it is more than 3 miles wide. Well-exposed sections of the sequence are found at this point of greatest width and also on Blackthorn Peak and the ridges leading north and south from it. The general strike of the beds ranges from north to N. 30° E. and the dip from 60° E. to 30° W. although there are wide local variations from this, especially in the Red Bed Peak and the Gullied Peak areas. This sequence may be conformable with the adjacent limestone sequence but evidence was not found that would definitely establish the relationship of the two.

The original sediments of the shale and graywacke sequence have been metamorphosed into a variety of rocks that in part reflect differences in composition and texture in the original sediments and in part result from differences in the size and character of the recrystallized mineral grains. All gradations from one type of rock to another are represented so that arbitrary limits must be set to the range of types included in each lithologic term.

The rock comprising the bulk of the metamorphic shale and graywacke sequence is a dark-purplish-gray rock with a granular texture that is called granulite in this report. Since the term "granulite" has been applied by different geologists to different types of rocks, it is well to stress that here the term applies to a medium-grained rock, granoblastic in microtexture, that lacks schistosity, lineation, and foliation. In places it has a relict bedding. The widespread usage of the term in this sense may serve as a precedent; it has been used thus in Canada (Adams and Barlow, 1910), Japan (Sugi, 1935), England (Read, 1931), and New South Wales (Joplin, 1942).

This granulite occurs in massive form and also in beds ranging from a few inches to several feet in thickness. Much of the granulite apparently formed by recrystallization from fine-grained sediments such as dolomitic shale, so that the coarseness of the texture is due to the size of the new mineral crystals. Some, however, has been derived from fairly coarse grained graywacke and arkose, and the texture is partly a relict clastic one inherited from the sediment.

In some areas the granulite bears a close resemblance to the sedimentary rock from which it was derived. For example, on the ridge north of Maynard Glacier it looks like a slightly metamorphosed graywacke, and on the cliff bordering the west side of the main tributary of Hugh Miller Glacier somewhat like recrystallized arkose. In other places it is a more thoroughly metamorphosed rock that not only has lost its original identity but grades into coarser-textured facies that are indistinguishable from hornblende-plagioclase rock and from diorite. On Blackthorn Peak beds of granulite alternate with beds of hornblende-plagioclase rock with infinite gradations both across and along the strike. The beds here range to a maximum thickness of 30 feet and include a few intercalated limestone beds. Still more intricate relationships with other rocks are found in zones where the granulite beds grade along their strike into interbedded complexes of granulite, hornblende-plagioclase rock, and gneissic diorite and diorite. One of the most accessible outcrops showing this gradation is found near the terminus of Geikie Glacier on the tip of the north ridge of Blackthorn Peak (p. 89).

The interfingering relationship between granulite, hornblende-plagioclase rock, and gneissic diorite extends all along the east side of the main belt of bedded rocks from Blackthorn Peak on the south through the ridges of Fossil Peak and Goat Ridge on into the Gullied Peak area on the north where the structure becomes less well defined and nearly all the types of rocks present in the quadrangle are literally scrambled in a chaotic pattern.

A granulite differing in composition from that previously described has formed from impure limestone, which has been metamorphosed into banded lime silicate rock. The bands, or beds, are composed of concentrations of diopside, garnet, and calcite respectively, and range from about a quarter of an inch to several feet in thickness. The intricate folding and the contrast of colors between beds give outcrops of this rock a vivid and bizarre appearance. The relative mobility of the calcite layers under stress has resulted in a pattern of folding that is ptygmatic. The more rigid garnet beds have as a result been fractured and in places show small overthrusts. The largest outcrop of this lime silicate granulite is exposed for hundreds of feet along the bluff bordering the east side of the south terminus of Charpentier Glacier. Outcrops are also found on the east side of Mount Skarn and in other places throughout the area.

Another type of rock that is abundant in the metamorphosed shale and graywacke sequence is a hornfels that occurs in thin, sharply delineated beds ranging from a small fraction of an inch to about 6 inches in thickness and aggregating a total thickness of possibly 5,000 feet. The beds are brightly colored with hues of red predominating but with shades of brown, white, yellow, and green common. This hornfels sequence forms a distinct unit that makes up the east side of the main belt of bedded rock in places and also forms isolated outcrops in other parts of the area. Although the hornfels sequence contains little if any granulite, the granulite sequence contains many beds of hornfels and the contact between the two units is a broad zone of interbedded granulite and hornfels.

The hornfels sequence is well exposed on Threesome Mountain, Contact Peak, Enigma Ridge, the ridge west of Enigma Ridge, and Red Bed Peak. The sections in these various outcrops differ some, especially in proportion of intercalated limestone beds, but in general they are closely similar. Where these outcrops are bordered by diorite, a transitional zone lies between the two. The contact between the hornfels and the diorite on the ridge west of Enigma Ridge includes a zone, 300 feet thick, of granulite that becomes progressively coarser grained away from the hornfels until it merges into dioritic gneiss. On the south side of the outcrop of hornfels on Red Bed Peak, the hornfels is bordered by 200 feet of white limestone, this in turn by 200 feet of hornfels and limestone, and this by gneissic diorite. The foliation in the diorite is parallel to the bedding in the hornfels.

Limestone beds make up a minor part of the metamorphosed shale and graywacke sequence and are largely limited to the granulite part. Some of the limestone beds are as much as 30 feet thick but most are only a few feet thick and in the hornfels many are less than an inch thick. Where deformation has been intense, the limestone in places has become mixed with adjacent rock. In some places isolated masses of limestone are incorporated into hornblende-plagioclase rock and in other places the reverse is true. In an outcrop on the north end of the ridge north of Blackthorn Peak near the terminus of Geikie Glacier, masses of hornblende-plagioclase rock form elongate pods within beds of deformed limestone. The fabric in these pods

FIGURE 12.—Limestone, *ls*, with enclosed masses of hornblende-plagioclase rock, *hp*, that recrystallized in part during deformation of the limestone. Hornblende-plagioclase rock may have been derived from dikes in limestone. Note parallel alinement between structures in limestone and outer margins of hornblende-plagioclase rock.

shows that the final crystallization of the hornblende-plagioclase rock took place after the original mass was incorporated into the limestone and before the deforming stress was relieved (see fig. 12).

Mafic igneous rock forms layers in the sequence of granulite and hornfels, but the total amount is not known as its appearance in the field is quite similar to that of the granulite. All of these igneous rock layers are conformable with the beds in the adjacent rocks; some were emplaced as surface flows of lava as is indicated by vesicular structures, and others were probably emplaced as sills. They are all readily distinguished from the more recent diabasic dikes because the latter everywhere cut across the bedding.

PETROGRAPHY

Most of the granulite and hornfels rocks have been completely recrystallized but some retain a relict clastic texture. The completely recrystallized granulite has been derived from arenaceous rock, from shale including calcareous and dolomitic shale, and from impure limestone. Granulite with relict clastic texture has been derived from arkose and graywacke and a small amount from impure limestone. The hornfels has been derived entirely from fine-grained rock, including shale and impure limestone; a small amount of it has retained a fine-grained relict clastic texture.

GRANULITE

A few outcrops of granulite with a composition corresponding to arkose were found in which no relict textures were apparent even though most of the arenaceous rock in the area has retained at least vestiges of a coarse clastic texture. One outcrop of this variety of granulite lies on the south side of the terminus of Geikie Glacier; the mineral composition of a specimen of it (150F) as given below indicates the abundance of felsic material in the sediment.

Mineral composition, in percent by volume, of two layers of granulite derived from arenaceous rock

Rock and specimen No.	Plagioclase [1]	Quartz	Hornblende	Epidote	Diopside	Prehnite	Sphene	Apatite	Pyrite
Granulite:									
Hornblende band; 150F	41	37	20	-----	2	-----	-----	-----	-----
Diopside band; 150F	44	29	1	Tr.	25	Tr.	Tr.	Tr.	Tr.

[1] An_{27}.

Most of the granulite in the area has been derived from fine-grained sediments, and has a completely recrystallized texture. Hornblende and diopside are the predominant mafic minerals, and oligoclase or andesine and quartz are the predominant felsic minerals. The texture is primarily granoblastic with some porphyroblastic development of plagioclase and poikiloblastic growth of hornblende. The composition of typical specimens of this rock are given below. Brief descriptions of diagnostic features in these specimens follow.

Granulite derived from calcareous shale

[Composition in percent by volume]

Rock and specimen No.	Plagioclase	Quartz	Hornblende	Biotite	Diopside	Calcite	Prehnite	Sphene	Apatite	Magnetite	Pyrite	Chlorite
Granulite 120	30 [1]	5	55	5	-----	2	-----	Tr.	Tr.	-----	Tr.	-----
Granulite 121	50 [2]	-----	40	1	-----	2	3	-----	3	-----	-----	-----
Layered granulite; 142E1:												
Bed 1	80	-----	20	-----	-----	-----	-----	-----	-----	-----	-----	-----
Bed 2	40	-----	60	-----	-----	-----	-----	-----	-----	-----	-----	-----
Bed 3	50	-----	40	-----	10	-----	-----	-----	-----	-----	-----	-----
Beds 4 and 6	-----	4	4	-----	-----	90	-----	-----	-----	-----	2	-----
Beds 5 and 7	-----	Tr.	Tr.	-----	Tr.	97	-----	-----	-----	-----	Tr.	-----
Foliated granulite; 236	20	30	43	-----	-----	Tr.	-----	-----	-----	-----	-----	5
Foliated granulite; 151J2	30 (An_{60})	20	48	-----	-----	-----	-----	-----	Tr.	Tr.	-----	Tr.
Foliated granulite; 151K1	35 (An_{50})	-----	48	15	-----	-----	-----	-----	-----	Tr.	-----	Tr.

[1] Oligoclase. [2] Andesine.

Typical granulite grading to a grain size coarse enough to resemble fine-grained diorite is represented in specimens 120 and 121, which were taken from outcrops showing well-formed beds. These rocks were derived from a somewhat dolomitic shale, and in them the hornblende and plagioclase are poikiloblastic.

With the exception of the few relict clastic quartz and plagioclase grains, the texture is granoblastic and in some places porphyroblastic. In certain bands the biotite and the tremolite crystals are oriented parallel to the bedding, yielding a lepidoblastic texture.

PETROGENESIS

The scarcity of beds containing biotite and hornblende crystals with a preferred orientation is evidence that the conditions under which the shale, graywacke, and arkose of this area were metamorphosed into hornfels and granulite involved little stress.

The mineral assemblages in the granulite and hornfels indicate that the temperature of metamorphism was near the mesozonal-katazonal boundary.

DIORITE

OCCURRENCE AND DISTRIBUTION

Bodies of diorite ranging from 25 feet to 12 miles long are distributed throughout the area and together total about one-third of the exposed bedrock. These bodies generally have very irregular outlines, and their margins consist of broad zones of hybrid types of rock. Most of the diorite has a fabric that is parallel to the bedding of the metasedimentary rocks in the area, and parts of it contain many inclusions of bedded rock that retain an orientation that is parallel to the foliation in the diorite. These features suggest that the diorite may be metamorphic rather than igneous in origin, and other criteria described below tend to corroborate this hypothesis.

The largest of what may be considered a single body of diorite lies along the east side of Brady Glacier where it is exposed in a chain of nunataks extending about 12 miles from north to south and about 4 miles from east to west at the widest place. The western boundary of this body lies concealed under Brady Glacier and may be as much as 3 miles west of the exposed margin. The eastern boundary of the body is a contact with bedded metamorphic rocks, mostly concealed under Geikie Glacier. The northern boundary is indefinitely indicated by outcrops of bedded rocks on scattered nunataks, and the southern boundary is a contact with intrusive granodiorite. A detached block of what was once part of the diorite mass is exposed as a roof pendant on the granodiorite a mile east of Abyss Lake. Although the rock of this body has the wide variation in texture typical of diorite in the region, it is notably lacking in inclusions of bedded rock, which are so common throughout other parts of the area.

Diorite also underlies much of the eastern third of the mapped area where it is exposed in many isolated outcrops. The most extensive continuous exposure of diorite here extends from Serrated Peak northward along the ridge flanking the west side of the Wood Lake valley and ends at the glacial outwash plain formed by Geikie Glacier. East of the Wood Lake valley, diorite is exposed on Mount Wood but it contains a considerable admixture of bedded rocks. The same condition exists in the area from Mount Wood to the east boundary of the mapped area where diorite constitutes most of the bedrock, but inclusions of bedded rocks are somewhat less abundant.

North of Geikie Inlet, diorite forms the northeast half of Mount Bulky and all of the ridge bordering the northwest side of Geikie Inlet between Mount Bulky and the valley that forms a low divide between Favorite Fiord and Geikie Inlet. The diorite in this exposure is relatively free of inclusions of bedded rock. North of this exposure an irregular-textured diorite containing many inclusions of bedded rock underlies most of the area between Red Bed Peak and Favorite Fiord. On the southeast it is in contact with massive gray limestone and on the west with a thick section of red hornfels beds. A continuation of this diorite mass is exposed to the northeast where it makes up the bulk of Mount Favorite and Hugh Miller Mountain. Here also the diorite contains inclusions of bedded rock although in the central parts of the two mountains these inclusions are scarce. Around the bases of the two mountains the diorite has an intricate and interfingering relationship with bordering bedded rocks.

Between Charpentier Inlet and the terminus of Hugh Miller Glacier diorite is exposed in many isolated outcrops that are sporadically distributed among outcrops of bedded rock. The largest body of diorite is exposed in part along the west shore of Charpentier Inlet where it forms a hill approximately 2 miles long. The only other relatively large mass of diorite in this area is on the west flank of Gullied Peak where it covers an area about a mile long and is bounded in part by a small granodiorite body and in part by bedded rocks.

DESCRIPTION

The diorite in this area has a wide variety of appearances that reflect variations in texture, structure, amounts and types of included material, and contact relationships. Most of it is spotted with inclusions composed of fine-grained mafic diorite, which have discoidal shapes and lie in a preferred orientation. Where these inclusions are lacking the rock generally has faint to prominent gneissic banding. Textural irregularities are conspicuous and result from both wide variations in grain size and the irregular, porphyroblastic shapes of the larger hornblende crystals. These irregularities are most accentuated in the marginal zones of the individual diorite bodies where migmatitic structures prevail. Masses of diorite that have a uniform appearance are present in only a few places and over areas a few hundred feet in diameter at the maximum.

The diorite cannot be summed up in one general description because of the diverse types present. Instead of a general description, individual descriptions of the more common types of diorite follow; divisions between types are of necessity somewhat arbitrary.

A small amount of diorite has a uniform, coarse texture, lacks inclusions of either bedded rock or more mafic diorite, and is without an oriented fabric. It is limited generally to masses a few hundred feet in diameter, which grade into the other types of diorite that surround these masses. Slightly more abundant than this is a uniform, coarse-textured diorite, which differs from that above in that the hornblende crystals have a preferred linear orientation. The two largest areas of this type of diorite are each less than 1,500 feet long; one is just north of Eerie Lake and the other is on the next ridge 2 miles farther north.

A type of diorite far more abundant than the above two incorporates a variety of textures, compositions, and appearances, and lacks an oriented fabric. On a large scale the appearance of this heterogeneous diorite is mottled and patchy, with noticeable differences occurring within distances of a few feet to a few hundred feet. Textures range from medium- to coarse-grained and compositions from mafic diorite to nearly a granodiorite. Individual masses of this diorite range from a few hundred feet to several miles across and are exposed at random over the mapped area. One of the largest masses of heterogeneous diorite makes up the bulk of Serrated Peak and part of the ridge to the northwest, and another forms the cliff walls bordering Favorite Fiord.

More than three-quarters of the diorite in the mapped area contains a profusion of rounded to irregular inclusions composed of darker colored diorite. The inclusions are darker than the host diorite partly because of their finer grained texture and also because of their higher content of hornblende and biotite. On the basis of shape these mafic inclusions roughly fall into two categories. The first and more abundant type has a discoidal form with a diameter several times as great as the thickness, and ranges from a few inches to as much as 2 feet in diameter, with most of the inclusions averaging about 1 foot in diameter. The second type has an irregular shape in plan but is decidedly flattened, presents an elongate, stringy outline in cross section, and typically ranges from several inches to 4 or 5 feet in length. Both types of inclusions in most places have a preferred planar orientation parallel to one or the other of the prevailing structural trends of the area, namely north or N. 45° E.

The inclusions range from dark, fine-grained bodies that stand in sharp contrast to the host diorite, to faint, coarse-grained shadowy patches that are apparent only by their slightly darker shade. Borders of the inclusions range from sharp and definite to

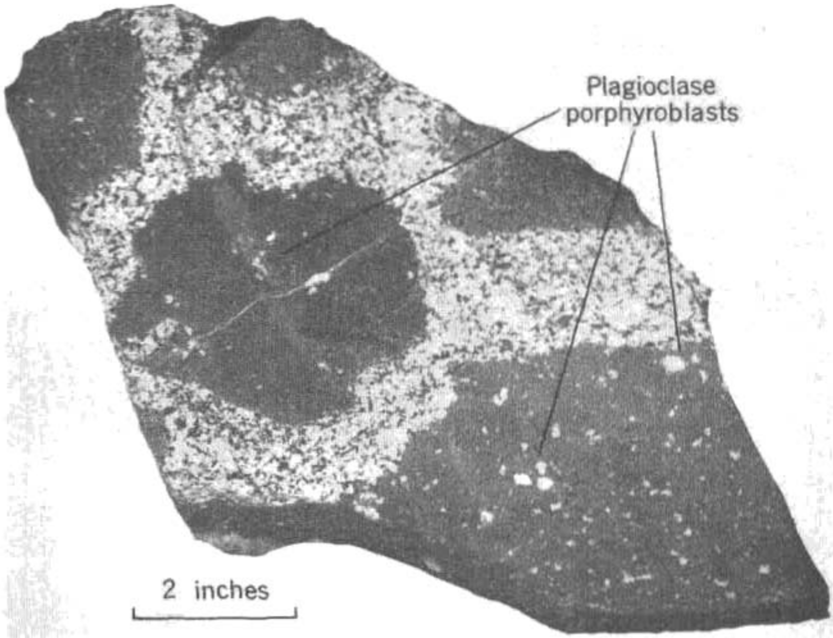

FIGURE 13.—Specimen of diorite with inclusions that have been replaced in varying degrees. Most inclusions have plagioclase porphyroblasts, and some, such as the inclusion at the top of specimen, have gradational borders that merge into the diorite.

broadly gradational, with the coarser grained texture of the host diorite penetrating irregularly into the inclusion. In many inclusions large porphyroblasts of plagioclase have developed and in places small patches of coarse-grained rock identical to the host diorite have formed within the inclusions. All these features are shown in the specimen pictured in figure 13.

The abundance of inclusions in the diorite varies greatly from place to place. In most areas inclusions are spaced less than 100 feet apart, and in some localities such as those shown in figure 14 the inclusions are spaced only a few inches apart.

A minor amount of the diorite contains some form of gneissic banded structure. The uniformity and continuity of the banding varies greatly and depends in part on the origin of the particular gneissic structure. The gneissic diorite in every outcrop observed is adjacent to or mingled with diorite containing commonly oriented elongate inclusions. In some outcrops elongate inclusions progressively grade to longer bands and finally to a banded gneiss. An example of stringy inclusions interspersed with tenuous mafic bands is shown in figure 15.

PETROGRAPHY

The diorite is composed largely of plagioclase ranging from oligoclase to andesine, hornblende, quartz and biotite in that order of

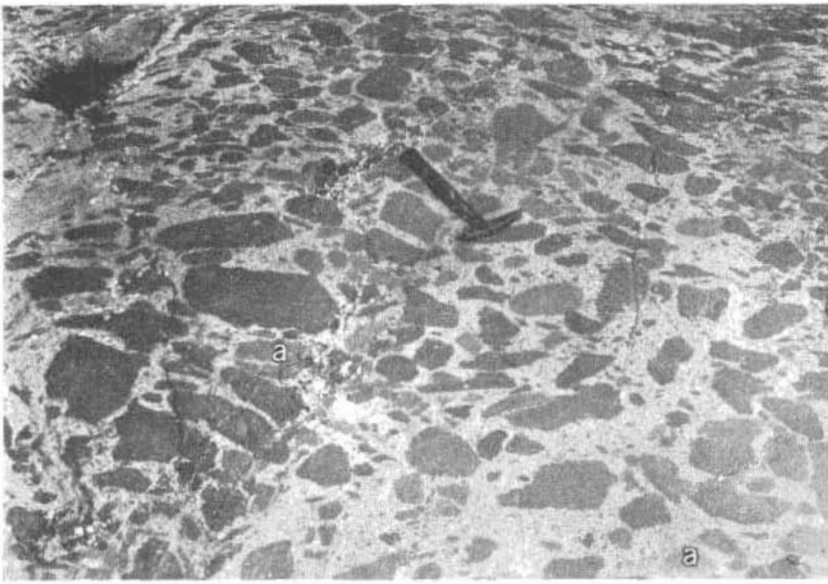

FIGURE 14.—*Outcrop of diorite with unusual abundance of mafic inclusions, a, that are similar in texture and composition to the host diorite.*

abundance, although biotite or quartz may be absent in some diorite, and biotite may be more abundant than hornblende in other diorite. Apatite, sphene, and magnetite are the most common accessory minerals, and prehnite, clinozoisite, and chlorite are the most common secondary minerals. Microtexture ranges from xenoblastic and por-

FIGURE 15.—*Gneissic diorite (1) with elongate granulite inclusions (2). White spots on the inclusions are plagioclase porphyroblasts.*

phyroblastic to nearly hypidiomorphic, and some of the gneissic diorite has foliated microstructure.

The greater part of the diorite has xenoblastic texture and commonly contains poikiloblastic hornblende and porphyroblastic plagioclase. A typical example is specimen 283 in which hornblende has replaced some plagioclase, a small amount of biotite has replaced hornblende, and chlorite has replaced some of the biotite. Commonly in the diorite the centers of plagioclase crystals have been largely altered to prehnite or zoisite but the rims are fresh and clear, indicating that some porphyroblastic growth took place after the alteration of the original grains.

Much of the diorite has a foliated structure formed by parallel layers or aggregates of hornblende or, less commonly, biotite or diopside. Normally the mineral grains in these layers have their long axes in the plane of foliation. The specimen shown in the photomicrograph in figure 16 shows this foliation with three variations; in

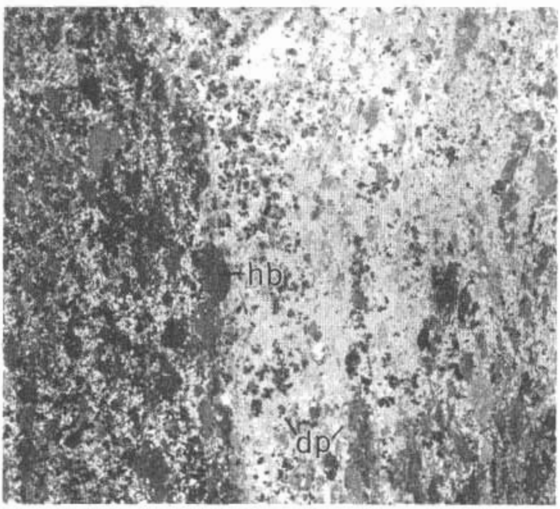

FIGURE 16.—Diorite with bands alternately rich in hornblende, *hb*, and diopside, *dp*. ×3.

the first band the mafic layers are formed by hornblende only, in the second layer by diopside only, and in the third layer by both together. The hornblende throughout has a poikiloblastic texture, and in the third layer has replaced some of the diopside.

Diorite having more regular xenoblastic texture is also common in the mapped area. In some of this rock, the mineral grains have straight boundaries that do not conform to their crystal boundaries which results in a pavement type of texture. In other masses of this rock, later growth of plagioclase and quartz crystals has produced a porphyroblastic texture superimposed on the predominant xenoblastic texture. Mafic inclusions that are incorporated in this type of diorite commonly have a granoblastic texture. A thin section of this diorite containing part of a mafic inclusion reveals this textural difference and also indicates that the mafic inclusion contains a higher percentage of sodium, calcium, magnesium, iron, and aluminum, and a lower percentage of potassium and silicon than the coarser grained host rock. In the coarse-grained part biotite has replaced some plagioclase, quartz has replaced biotite and plagioclase, and chlorite has replaced biotite.

Diorite from a transitional zone between diorite containing oblate mafic inclusions and diorite with gneissic banding is represented by specimen 77. In this rock orthoclase and quartz have replaced plagioclase extensively, and chlorite, epidote, and prehnite have replaced or formed in the biotite. The finer grained part of the specimen representing a mafic inclusion has a granoblastic texture. In this part the biotite has replaced some hornblende, and the plagioclase has been more altered to prehnite and clinozoisite than has the plagioclase in the coarser part. Apparently the coarser part has been enriched in silica and potash, resulting in the porphyroblastic growth of orthoclase and quartz.

Some of the more felsic, coarser grained diorite has relatively well formed plagioclase crystals interspersed with clear quartz grains. Mafic inclusions and bands in this type of diorite have granoblastic textures and contain plagioclase porphyroblasts. The photomicrograph in figure 17 shows this coarser texture as well as the prehnite blebs enclosed in biotite.

The following table lists the composition of various representative specimens.

Mineral compositions of different types of diorite

[Composition in percent by volume]

Rock and specimen No.	Plagioclase	Quartz	Orthoclase	Hornblende	Biotite	Epidote	Clinozoisite	Diopside	Prehnite	Chlorite	Sphene	Apatite	Magnetite
Porphyroblastic diorite:													
136A	55 (An_{35})	2	----	40	2	----	Tr.	----	Tr.	----	----	----	Tr.
283	60 (An_{30})	10	----	25	3	----	----	----	----	Tr.	Tr.	----	Tr.
Foliated di)rite:													
214	73 (An_{25})	----	----	25	----	----	Tr.	----	Tr.	----	----	Tr.	Tr.
213:													
Band 1	35 (An_{35})	----	----	63	----	----	Tr.	----	----	----	Tr.	Tr.	Tr.
Band 2	55 (An_{45})	----	----	----	----	----	----	42	----	----	Tr.	Tr.	----
Band 3	42	----	----	35	----	----	----	25	----	----	Tr.	Tr.	----
Diorite with pavement; 77:													
Coarse-textured band	50 (An_{30})	25	5	1	15	Tr.	----	----	Tr.	Tr.	Tr.	----	----
Fine-textured band	55 (An_{20}	8	----	15	20	Tr.	----	----	Tr.	Tr.	----	----	Tr.
Coarse-textured part	53 (An_{30})	22	----	8	15	----	----	----	----	Tr.	Tr.	Tr.	Tr.
Fine inclusion	58 (An_{30})	3	----	32	5	----	----	----	----	----	Tr.	----	Tr.
Coarse-textured diorite:													
57	60 (An_{30})	15	----	5	20	----	----	----	----	----	----	----	----
54:													
Coarse-textured band	65 (An_{30})	25	----	----	10	----	----	----	----	----	----	----	----
Fine-textured band	70 (An_{33})	----	----	25	3	----	----	----	----	----	Tr.	Tr.	Tr.

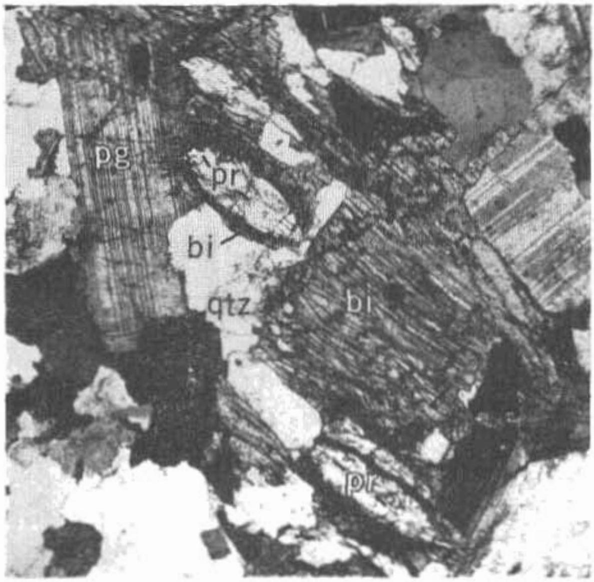

FIGURE 17.—Diorite with prehnite aggregates enclosed by biotite. Plagioclase, *pg;* quartz, *qtz;* biotite, *bi;* and prehnite, *pr.* ×20. Crossed nicols.

CONTACT RELATIONS

Contacts between diorite bodies and bedded rock are typically gradational across the strike of the bedding and foliation, and several are gradational along the strike. Where this gradation was observed, the fabric in the diorite was parallel to the bedding or schistosity of the adjacent metamorphic rock. Examples of this orientation are found in many places. One of these is on Contact Nunatak at the east border of Brady Glacier where a sequence of thin beds that were originally shale and graywacke and now are metamorphosed to amphibole, chlorite, and biotite schist grade southwestward into a dioritic gneiss containing thin bands composed largely of tremolite and biotite. There is no definite contact, as beds or layers of schist and diorite alternate over a zone several hundred feet wide, with the layers of each type becoming progressively less abundant toward the main mass of the other type of rock. The strike and dip of the schistosity and the gneissic structure remain constant throughout the zone of contact.

A broad, gradational, and conformable contact between coarse-textured gneissic diorite and a sequence of granulite and hornfels beds is well exposed along the main east ridge of July Fourth Mountain, about 1½ miles southeast of the summit. This contact occupies a zone of transitional rock several hundred feet wide, with a continuous gradation from fine-grained hornfels on the east to coarsely crystalline diorite on the west. The gneiss, the transition rock, and the granulite and hornfels beds all have the same strike and dip.

At Favorite Creek, where a gradation across the strike from granulite to foliated and gneissic diorite is well exposed, the gneissic diorite grades without a break into bedded metamorphic rock.

The most intricate and interfingering contact between granulite beds and gneissic diorite observed in the area is exposed along the base of the mountain ridge north of Blackthorn Peak, at the northeast end. This outcrop is adjacent to the present terminus of Geikie Glacier. The contact zone is about 1,000 feet wide across the strike, is bordered on the east by diorite, on the west by interbedded limestone, granulite, and amphibolite, and on the south along the strike by bedded granulite. All rocks in this area have approximately the same strike and dip. Within the contact zone, beds of granulite and layers of gneissic diorite are intimately associated on a minute scale. Individual layers of granulite range from a sixteenth of an inch to several feet in thickness and are separated by diorite layers ranging from about a quarter of an inch to several feet in thickness. Figures 18, 19, and 20 show typical examples of the relationship between the two types of rock. In places lenticular masses of granulite lying in the gneissic diorite are connected by tenuous filaments of granulite with no indication of disturbance or displacement of any part of the granulite masses. Throughout the zone all the rocks maintain the

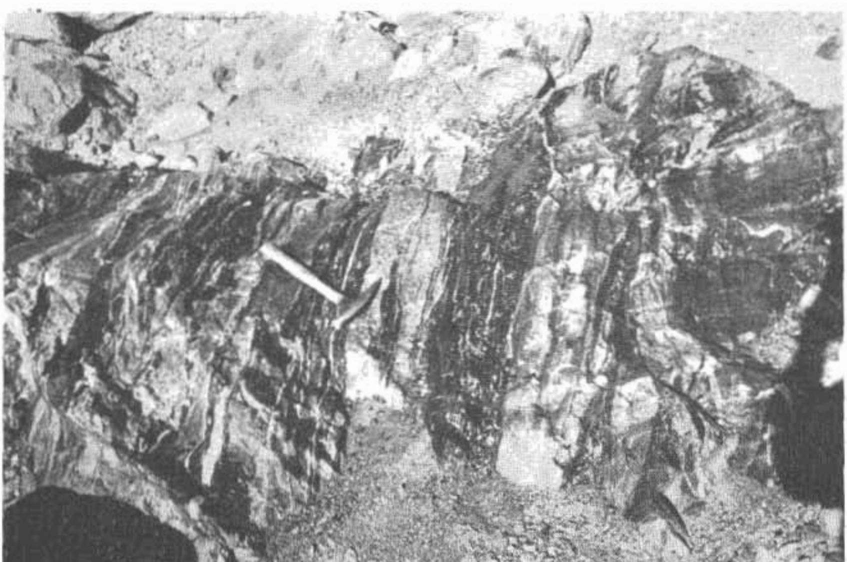

FIGURE 18.—Interfingering granulite beds and diorite.

FIGURE 19.—Detail of granulite-diorite relationship. All isolated fragments of granulite maintain an alinement with the continuous beds. Diorite (1), commonly oriented granulite fragments (2).

FIGURE 20.—Detail of gradational relationship between granulite and diorite. Diorite (1) has formed by replacement of the granulite (2). Rock intermediate between the two represents an intermediate state of recrystallization.

same orientation. Where the rock is more thoroughly recrystallized the interfingering of the granulite and diorite result in a dioritic gneiss containing lenticular mafic inclusions. Figure 15 shows an example from this contact zone. The mafic lenticular masses shown in this figure are spotted with plagioclase porphyroblasts.

The petrography of several specimens taken across the contact at the Contact Nunatak locality, and across the strike of interfingering metamorphosed bedded rocks and gneissic diorite at the Geikie Glacier terminus locality, furnishes additional information on the relationship between the diorite and the metasediments.

Four specimens from the Contact Nunatak locality include two of schist from the metamorphosed bedded rocks, specimens 251 and 253, and two of diorite with fine-grained amphibolite layers, taken about half a mile from the contact, specimens 248 and 249. The mineral compositions of these specimens is given below.

Compositions of four rocks from a contact zone

[Composition in percent by volume]

Rock and specimen No.	Plagioclase	Quartz	Tremolite	Hornblende	Biotite	Epidote	Prehnite	Chlorite	Sphene	Apatite	Magnetite
Diorite 249:											
Coarse-textured band	70 (An_{36})	------	------	29	------	------	Tr.	Tr.	1	Tr.	------
Fine-textured band	27 (An_{25})	------	------	69	------	------	2	------	Tr.	Tr.	------
Diorite 248	18 (An_{30})	------	------	72	------	------	3	6	Tr.	Tr.	------
Schist 253	17	------	------	65	12	2	3	------	------	------	Tr.
Schist 251	29 (An_{20})	1	28	------	6	Tr.	17	18	Tr.	------	------

The feature that relates these four specimens is the similar biotite and amphibole-rich layers in both the schist and the diorite. Progressively away from the schist, layers of intercalated diorite become more abundant until a point is reached several hundred feet from the schist beyond which thin layers of biotite and amphibole in the diorite are the only relicts of the schist. These mafic layers continue throughout the rest of the exposed diorite to a point more than 2,000 feet from the schist.

In the schist represented by specimen 251 some layers are composed almost entirely of commonly oriented tremolite and brown chlorite, and others are of clastic quartz and plagioclase grains surrounded by tremolite and brown chlorite. The structure resulting from this layering is an incipient gneissose one. Further crystalloblastic growth of the plagioclase and quartz would produce a texture comparable to that in the dioritic gneiss, which is exposed 5 feet away from this banded schist. The petrographic features of the banded schist are shown in figure 21.

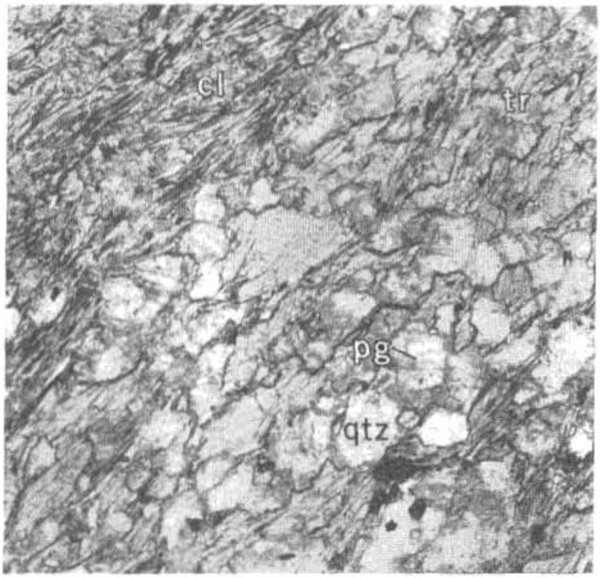

FIGURE 21.—Photomicrograph of band schist with incipient gneissic structure. Clastic quartz, *qtz*, and plagioclase grains, *pg*, interspersed with alined brown chlorite, *cl*, and tremolite, *tr*. × 40.

The other two specimens cited from the Contact Nunatak area contain mafic bands representing the dark bands of the gneissic diorite. These mafic bands are principally of hornblende crystals oriented parallel to the layer in which they lie, and are similar in composition, structure, and texture to some of the layers in the schist. A photomicrograph of a specimen of diorite with a mafic band (specimen 249) taken half a mile from the schist, is shown in figure 22 for comparison with the photomicrograph of the schist specimen. Figure 23 of this same thin section shows a plagioclase porphyroblast along the border between the fine-grained mafic band and the coarse-grained diorite.

In the zone of interfingering granulite, dioritic gneiss, and hornblende-plagioclase rock at the terminus of Geikie Glacier, the interbedding is on so small a scale in places that several layers will be present in an inch of the rock. The granulite is represented by the finer grained, more mafic layers and the diorite by the coarser grained, more felsic ones. Textures are crystalloblastic throughout, and the dioritic layers appear to represent layered zones in the original granulite that became coarser grained because of either an originally higher quartz content or the preferential introduction of quartzose solutions along these planes. In the following table the mineral compositions of several of these alternating layers is given. An example of this

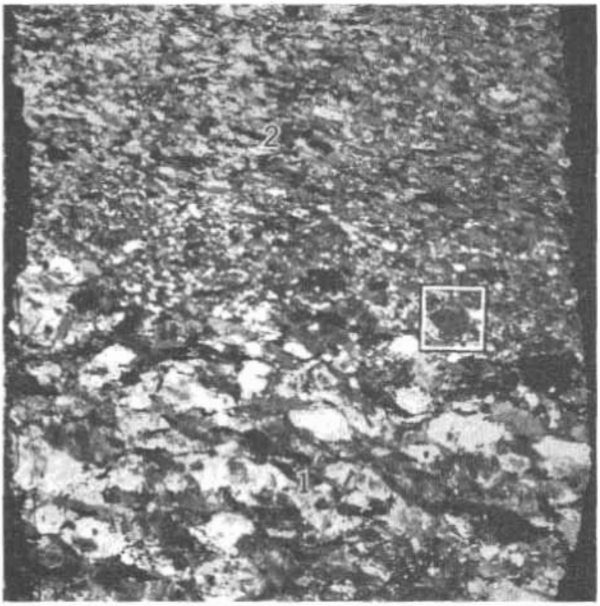

FIGURE 22.—Diorite containing fine-grained mafic band composed largely of commonly oriented hornblende crystals. This mafic band is nearly identical to many bands in adjacent schist. (1) Porphyroblastic diorite, (2) fine-grained mafic band. × 3. Crossed nicols.

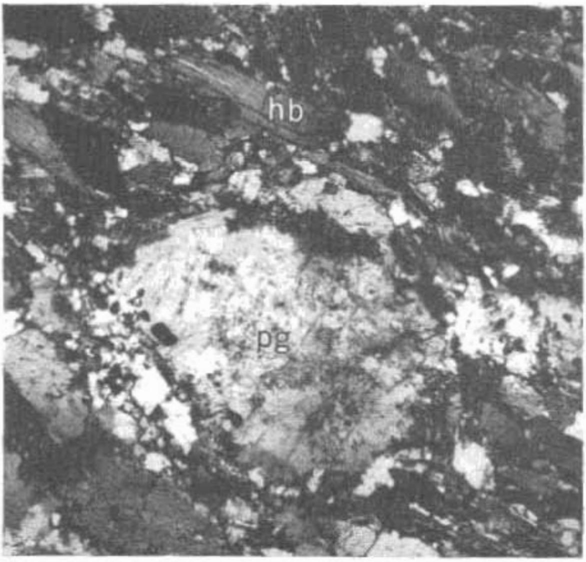

FIGURE 23.—Detail from figure 22. Plagioclase porphyroblast, along border between mafic band and coarser diorite has grown extensively and included much material. Plagioclase, *pg*, hornblende, *hb*. × 30. Crossed nicols.

Compositions of several zones near Geikie Glacier terminus

[Composition in percent by volume]

Rock and specimen No.	Plagioclase	Quartz	Orthoclase	Hornblende	Augite	Sericite	Biotite	Diopside	Prehnite	Chlorite	Sphene	Apatite	Magnetite
Gneissic diorite, 150E:													
Coarse-grained band	37 (An_{33})	11	----	16	35	----	----	----	----	----	Tr.	Tr.	----
Fine-grained band	37 (An_{35})	----	----	63	----	----	----	----	----	----	----	----	----
Medium-grained band	46 (An_{33})	4	----	50	----	----	----	----	----	----	----	----	----
Coarse-grained band	40 (An_{35})	58	----	2	----	----	----	----	----	----	----	----	----
Fine-grained band	32 (An_{33})	----	----	28	----	----	39	----	----	----	----	----	Tr.
Medium-grained band	44 (An_{35})	15	----	39	----	----	1	----	----	----	Tr.	Tr.	----
Gneissic diorite, 150F1	41 (An_{38})	26	----	16	----	2	----	9	----	4	----	Tr.	----
Diorite, 150F2:													
Light band	48 (An_{27})	41	2	----	----	----	8	----	Tr.	Tr.	----	----	----
Dark band	67 (An_{35})	7	----	23	----	----	2	----	Tr.	Tr.	----	----	----

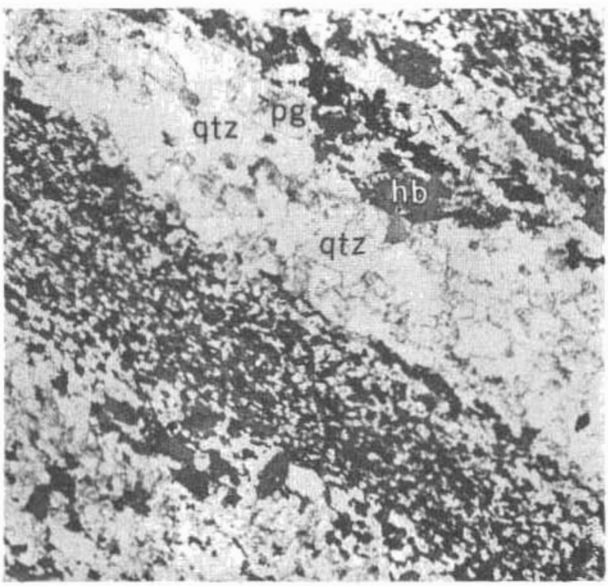

FIGURE 24.—Zone of interfingering granulite and diorite. × 9. Plagioclase, *pg*; quartz, *qtz*; hornblende, *hb*.

type of rock is shown in figure 24. In this specimen poikiloblastic hornblende has replaced some augite. In some layers diopside forms the predominant mafic mineral. The diopside in specimen 150F1 is distributed in this manner.

A type of rock found in this outcrop that is a variation from the types represented by the above two specimens is a gneiss containing augen-shaped porphyroblasts of hornblende and plagioclase. An example of this rock is shown in figure 25. This rock may have been derived from an old volcanic or dike rock, as it contains plagioclase porphyroblasts with highly altered cores which may represent relict plagioclase phenocrysts. The hornblende displays the typical poikiloblastic habit. These features are shown in figure 26.

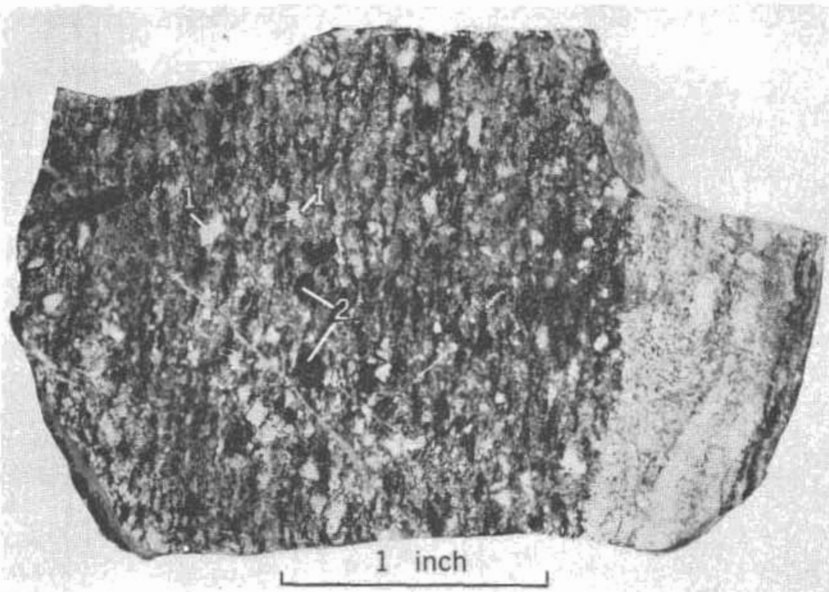

FIGURE 25.—Gneissic diorite with porphyroblastic texture. Plagioclase porphyroblasts (1), hornblende porphyroblasts (2).

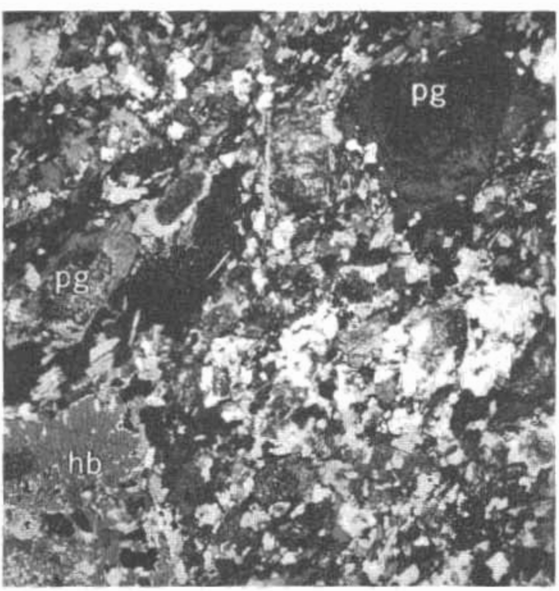

FIGURE 26.—Detail of specimen in figure 25. Poikiloblastic development of hornblende, *hb*, visible in lower left corner; porphyroblastic expansion of plagioclase, *pg*, crystals visible in upper part. × 18. Crossed nicols.

INCLUSIONS OF BEDDED ROCK

Masses of bedded hornfels, granulite, and limestone are included in large amounts through much of the diorite. These inclusions range from small masses an inch or so in length to masses more than 100 feet in thickness and over a mile in length. Most of them are oriented parallel to the gneissic structure of the enclosing diorite and also to the structure of large masses of bedded country rock in the vicinity. Also present are many inclusions lacking preferred orientation, and showing little or no continuity with adjacent inclusions. Some of the zones in which these occur show evidence of early faulting and brecciation. The included rocks mostly show a higher degree of recrystallization only at their borders, and the diorite shows no effects of chilling even at the contacts with the largest included masses.

The stream that drains from the southeast into the small lake below Wood Lake exposes diorite with included masses of bedded rock. Within the diorite, forming a 300-foot belt, are, a section of limestone 200 feet thick; a band of medium-grained mafic granulite which grades into well-bedded black hornfels and back to the granulite; and some more beds of limestone. The strike and dip of all the beds and also the gneissic diorite on both sides of this belt are the same.

In many places on outcrops of granulite, hornfels, and limestone the surface is ridged and grooved as a result of differences in resistance to weathering between adjacent beds. This same ribbed relief surface also appears in places in the diorite and lends the rock a bedded appearance, although a fresh fracture reveals only variations in grain size and proportion of mafic minerals. Examples are to be found in outcrops along the north summit ridge of Mount Wood about 4,000 feet south of the creek bed exposure described in the preceeding paragraph, and in other diorite outcrops throughout the area.

An excellent and extensive outcrop that reveals the relationship between gneissic diorite and included granulite beds occurs on the long narrow nunatak that lies between Brady Glacier and Aurora Glacier, 2 miles due west of Mount Friable. For a distance of more than half a mile across the strike, gneissic diorite is exposed that contains granulite beds in parallel orientation to the gneiss. They range from 1 to 6 inches in thickness with the exception of one bed, which is about 300 feet thick.

At several localities within the mapped area beds of limestone are found included in diorite. In every occurrence observed these beds lie parallel to the gneissic structure of the enclosing diorite. The largest continuous bed of limestone lying within diorite is exposed on Mount Skarn where it closely follows the summit ridge east of the summit. The bed ranges from 75 feet to about 200 feet in thickness and is exposed without a break for a length of 4,000 feet. Part of its length is bordered by granulite beds as much as 200 feet thick. These are highly recrystallized and from a short distance strongly resemble the diorite. This belt of limestone and granulite is bordered on both sides by gneissic diorite with the same structural orientation as the bedded rocks.

Related to this limestone bed on the summit ridge are three limestone beds enclosed in gneissic diorite and exposed on the west shore of Tyndall Cove. The beds lie along the projected strike of the summit ridge limestone, and they and the enclosing gneissic diorite have the same strike and dip. From north to south the beds are 10 feet, 20 feet, and 4 feet thick respectively, separated by 20 feet and 30 feet of diorite. The bedrock between this outcrop and the summit ridge belt is concealed so that one cannot be traced into the other. However, if they are all continuous and part of the same bed, they form an included bed of limestone more than 6,000 feet long.

A curiously similar example of brecciation and replacement in limestone instead of diorite is exposed on the north shore of Glacier Bay, 7 miles north of the northwest end of Hugh Miller Mountain. Here a black limestone has been brecciated, and the finely shattered material, along with parts of the larger blocks, has been replaced by calcite. The similarity of appearance and form between this and the brecciated diorite suggests a parallel in the processes by which the two were formed; that is, brecciation followed by permeation of solutions and recrystallization. In the limestone breccia, calcium was added and the dark carbonaceous material removed, and in the diorite breccia, quartz and possibly sodium were added and iron and magnesium were removed. Figures 27 and 28 show the similarity between the limestone and the diorite breccias.

A type of diorite related to the brecciated diorite contains abundant mafic inclusions that differ from the angular, blocky inclusions of the brecciated diorite in having more rounded shapes and gradational borders. In places the one form grades into the other, indicating that the rounded inclusions are partly replaced remnants of angular inclusions. The process that caused replacement of the finely crushed material apparently continued long enough in places to cause partial replacement of the larger fragments. Ragged, gradational borders and porphyroblastic plagioclase throughout many of the mafic inclusions are indications of this continued replacement.

PETROGENESIS

Field relationships and petrographic evidence suggest that the diorite in the mapped area was probably derived largely from bedded sediments and volcanic rocks. The evidence on which this conclusion is based has been described throughout the foregoing text so that a short summary will suffice here.

FIGURE 27.—Brecciated limestone (1) partly replaced by calcite (2).

FIGURE 28.—Brecciated diorite (1) partly replaced by feldspar (2).

Probably the feature that first suggests to one working in the area that the diorite may have been derived from the bedded rocks is the gneissic structure of the diorite, which is quite consistent in trend and parallel to the bedding of the metamorphosed bedded rocks in the area. In general these two major rock units have a strike ranging from north to N. 45° W. and dips ranging from 60° E. to 60° W. Where the strike locally diverges considerably from this, the fabric in adjacent diorite and bedded rock bodies is mostly parallel. This is interpreted as indicating that the diorite was formed by replacement of part of the original bedded rocks and that the fabric elements in the diorite are relicts of bedding from the replaced sediments. Additionally supporting this conclusion is the evidence furnished by the limestone beds that are conformably included within masses of gneissic diorite. More than ten of these included beds were observed, ranging in thickness from several feet to 200 feet and in length from about 100 feet to 4,000 feet. At each inclusion the bedding of the limestone, the fabric of the enclosing gneissic diorite, and the contacts between the two were all parallel. Furthermore, the undisturbed condition of the nearly mile-long limestone inclusion on Mount Skarn indicates that no apparent movement accompanied the incorporation of the limestone into the diorite. These relationships are interpreted to be the result of replacement of chemically favorable sediments by diorite, with chemically unfavorable beds, here the limestone, remaining unaffected and persisting locally as the only relicts of the former bedded sequence. Similar relict limestone beds conformably enclosed in a paragneiss have been reported from the Karakorum region of the Himalaya Mountains (Misch, 1949).

The many gradational contacts between diorite and bedded rocks throughout the mapped area also suggest a genetic relationship between the diorite and the bedded rocks. Evidence that these bedded rocks can be metamorphosed into diorite is furnished by the progressive gradation from hornfels to schist to gneissic diorite in the Favorite Creek and Contact Nunatak outcrops, by the interfingering and gradational relationships among granulite, hornblende-plagioclase rock, and diorite in Geikie Glacier terminus outcrop, and by the beds of dioritic rock in sequences of hornfels and granulite such as those on the south ridge of Gullied Peak and the north ridge of Blackthorn Peak.

The abundant mafic inclusions scattered throughout most of the diorite furnish little evidence in themselves regarding the origin of the diorite. The strong tendency of these inclusions to lie with a preferred orientation, however, does suggest one of these two possibilities of origin for the inclusions and in turn for the diorite: either the inclusions represent xenoliths that were rotated into a common orientation by differential movement within the plastic host rock as the latter was flowing, or else they are relicts of bedded rocks which retain the orientation of the original bedding. Both possibilities offer features difficult to explain, but the concept of a differential movement or flow in a plastic medium that would produce a parallel orientation throughout an entire body seems untenable. Differential flow in a flowing viscous body is a boundary effect and where the body is narrow, as in a dike, the effects from the two boundaries could extend to the center and yield a parallel planar fabric throughout. Where the body is relatively wide (miles wide in this area), however, it seems more likely that much of the central part of such a flowing mass would lack differential flow and therefore, transported inclusions in the central part would have a random orientation. Also it seems likely that in a plug-shaped mass of flowing material the differential movement would be parallel to the confining boundaries and would therefore leave a fabric concentric with the boundaries. Such a pattern is not to be found in the diorite bodies of this area. Instead the fabric extends straight across these bodies and is parallel to the boundaries only where the boundaries are in turn parallel to the bedding in the adjacent rock.

Two other features suggest that the inclusions are relicts of sedimentary rock and not xenoliths. One is parallel alinement of the disc-shaped diorite inclusions with adjacent inclusions of hornfels and granulite and with adjacent beds, in many different places. The other is the range of compositions of inclusions that are in close proximity. Granulite, fine-grained diorite, and limestone inclusions are close together at several localities.

Suggestion of a metamorphic origin for the diorite is found also in microtexture which is predominantly crystalloblastic, and shows an abundance of poikiloblastic hornblende and porphyroblastic plagioclase. The borders of individual mineral grains are generally irregular with considerable interpenetration between adjacent grains. Exceptions to this are found in several small areas where the diorite has an idioblastic texture with fairly regular mineral grain borders that do not correspond to crystal boundaries. These textural features seem to indicate an origin by recrystallization of bedded rocks rather than crystallization from a liquid mass.

The diorite is similar in both mineral and chemical composition to much of the hornfels, granulite, and hornblende-plagioclase rock. The chemical compositions of samples of these rocks are given below for comparison. All the variations fall within a range that would allow the metasediments to be recrystallized into the diorite with little change in composition.

Some metasomatism may have been active locally, as is indicated in the Contact Nunatak area, where the formation of diorite from schist was probably accompanied by the addition of silica and soda. Except for such local exchanges of components, the regional metamorphism was probably in large part isochemical. The mineral assemblages in the diorite and in the bedded metamorphic rocks indicate that the grade of metamorphism is probably near the katazone-mesozone border.

Chemical compositions of samples of eight crystalline rocks from the area

Specimen	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O
Diorite (1)	59.1	15.7	8.6	3.6	5.4	3.4	1.4
Diorite (83)	53.2	20.2	7.6	2.6	6.8	5.1	1.2
Diorite (85) (mafic inclusion)	49.8	19.4	9.8	3.8	8.2	4.2	.6
Hornblende-plagioclase rock (344)	63.3	14.2	10.0	.6	3.2	6.4	.5
Granulite (343)	57.2	16.3	6.5	3.8	7.4	5.4	1.4
Granulite (308)	49.3	13.6	14.5	5.4	7.2	4.4	.6
Granulite (103)	64.6	15.1	6.1	2.6	4.2	4.5	1.0
Hornfels (120)	51.3	13.6	13.6	3.8	8.0	4.2	1.0

HORNBLENDE-PLAGIOCLASE ROCK

OCCURRENCE AND DISTRIBUTION

The term hornblende-plagioclase rock is applied to a metamorphic rock composed essentially of hornblende, and oligoclase or andesine, and characterized by a texture coarser than that of granulite and less regular than that of diorite. Because it appears in places as the equivalent of the bedded rocks and in other places as a transitional rock bordering a diorite mass, its distribution over the area forms a patchy and erratic pattern. A few of the largest or more unusual occurrences will be described briefly here.

The most prominent exposure of bedded hornblende-plagioclase rock is on the west side of Blackthorn Peak, where the rock is interbedded with granulite, hornfels, and limestone. Combined, these form a sequence more than 2,000 feet thick. In places the hornblende-plagioclase rock forms entire beds several feet thick and hundreds of feet long, and in other places it forms small, tenuous patches within beds of hornfels and granulite. Three miles north of Blackthorn Peak, and approximately along the strike of the beds, is the outcrop of interfingering granulite, hornblende-plagioclase rock, and gneissic diorite described previously in connection with the granulite and diorite layers exposed at the Geikie Glacier terminus. Here the hornblende-plagioclase rock, in many small patches, appears to be a transitional phase between the granulite and diorite.

Immediately north of the terminus of Geikie Glacier is a scattering of outcrops of interbedded limestone, granulite, hornblende-plagioclase rock, and gneissic diorite. All beds follow the same strike, and except for the limestone, relationships among the different types of rock are gradational. From this area west to the crest of the south ridge of Fossil Peak, the hornblende-plagioclase rock includes types ranging from medium-fine-grained to coarse-grained, pegmatitic rock.

Large masses of hornblende-plagioclase rock chaotically associated with hornfels, granulite, diorite, and limestone are found on the plateau flanking the east side of Red Bed Peak, on the west flank of Gullied Peak, and on the ridge west of Threesome peak. Similar but smaller masses are found in other parts of the area.

DESCRIPTION

Much of the hornblende-plagioclase rock is structureless and its texture and grain size vary erratically within distances of a few inches. Hornblende crystals range from 2 to 40 millimeters in length but crystals less than 10 millimeters long are most common. As this rock has recrystallized from other rock it tends to form gradationally bounded patches and zones rather than well-defined bodies. Some of it forms wide and irregular zones bordering large diorite masses and some of it forms small irregular masses within hornfels and granulite beds. The irregularity of the texture of this rock is illustrated in figure 29.

Some of the hornblende-plagioclase rock has retained vestiges of the bedding of the granulite and hornfels from which it was derived. This is especially well displayed in the Blackthorn Peak area, where one specimen (see fig. 30) shows an appreciable gradation from

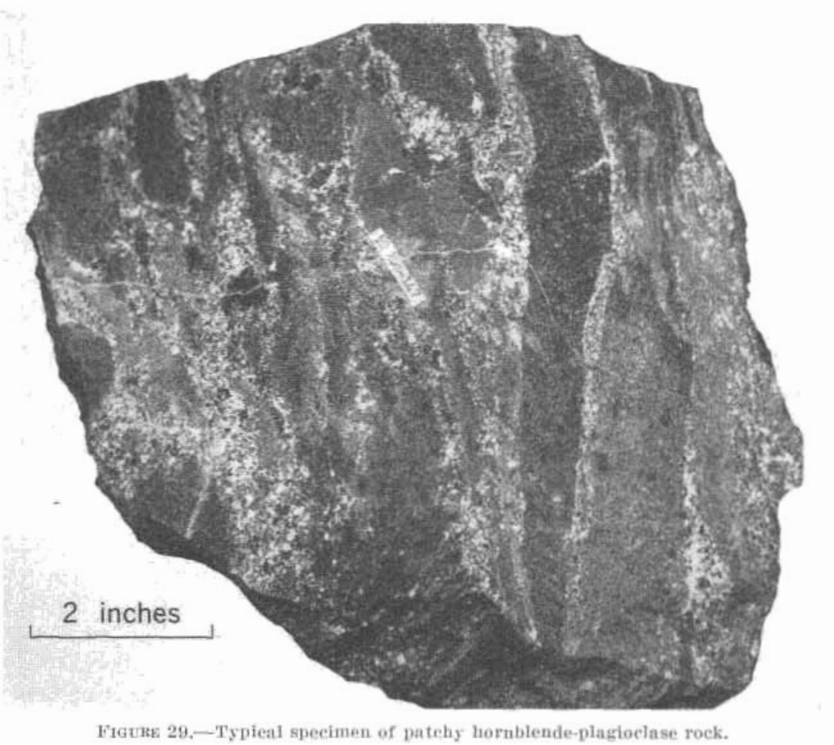

FIGURE 29.—Typical specimen of patchy hornblende-plagioclase rock.

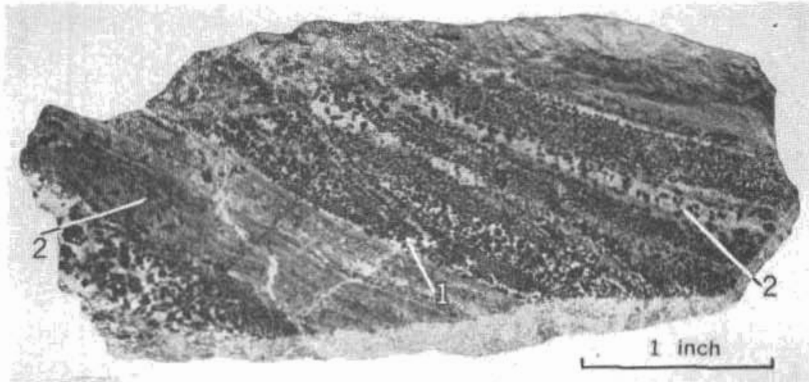

FIGURE 30.—Specimen of bedded hornfels and hornblende-plagioclase rock. Progressive development in size and abundance of poikiloblastic hornblende crystals along the strike of a hornfels bed is shown on the left side of the specimen. The structure in the bed above this may represent a relict drag fold. *Possible fold structure* (1), *hornblende porphyroblasts* (2).

hornfels to incipient hornblende-plagioclase rock within a distance of 2 inches along the strike of a bed. The first indication of the development of hornblende-plagioclase rock is the appearance of poikiloblastic hornblende crystals. In the bed adjacent to this, relict structure, possibly representing a drag fold in the original sediment, is discernible.

Gradations from hornfels and granulite to hornblende-plagioclase rock across the bedding are even more common than gradations along the bedding and in many places the beds in a sequence are composed alternately of hornblende-plagioclase rock and hornfels or granulite. This relationship, illustrated in figure 31, may result from differential metamorphism in which beds having a limited range in composition recrystallize to hornblende-plagioclase rock and beds of composition not in this range developed into hornfels or granulite. Extreme variations in texture and appearance may be developed within a small area as is shown by the boulder in figure 32.

PETROGRAPHY

Many thin sections of hornblende-plagioclase rock closely resemble those of diorite. Microtextures are largely similar except for a noticeably greater proportion of hornblende with sieve structure in the hornblende-plagioclase rock. Microstructures differ most where relict bedding is plainly visible in the hornblende-plagioclase rock. The thin sections described below are representative of several varieties of hornblende-plagioclase rock found in the area.

A sequence exposed along Favorite Creek offers a comparison of rocks produced by recrystallization from beds of differing composition. The following table gives the mineral composition of three different specimens from this sequence.

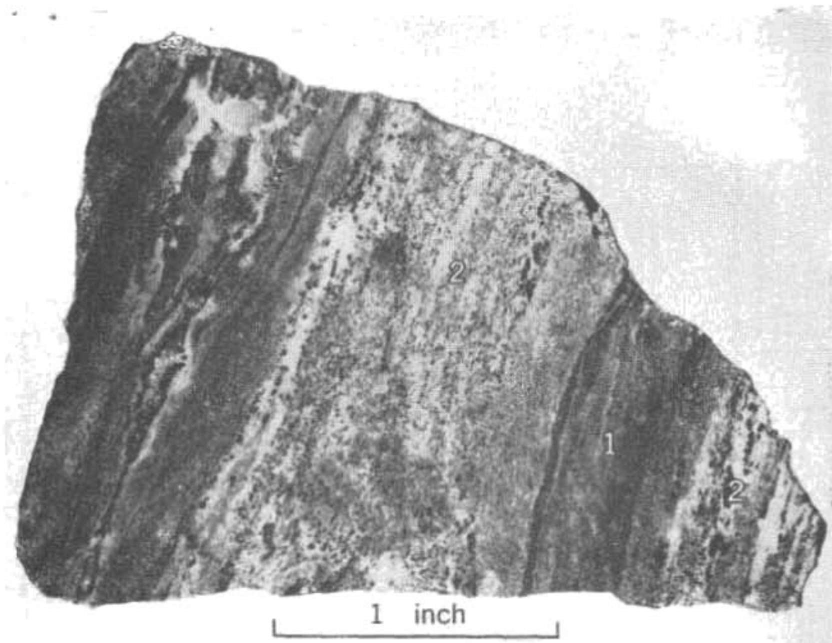

FIGURE 31.—Rock in which the more calcareous beds recrystallized to fine-grained lime-silicate granulite (1) and the argillaceous beds recrystallized to medium- and coarse-grained hornblende-plagioclase rock (2).

FIGURE 32.—Example of variations in texture and structure common in hornblende-plagioclase rock. Mottled (1), banded (2).

Mineral composition of granulite and hornblende-plagioclase rock from Favorite Creek

Specimen No.	Rock name	Plagioclase	Quartz	Hornblende	Augite	Biotite	Epidote	Clinozoisite	Orthite	Calcite	Grossularite	Scapolite	Sphene	Apatite	Magnetite
343	Bedded granulite	60[1]		8	20	10								Tr.	
[2] 344a	Gneissic hornblende-plagioclase rock with lime-silicate layer.	25 (An_{35})	20	5	18			Tr.	1	2	10	10	3	Tr.	6
344	Gneissic hornblende-plagioclase rock	40 (An_{40})	20	25	5	5	2			Tr.				1	2

[1] Oligoclase.
[2] Average composition.

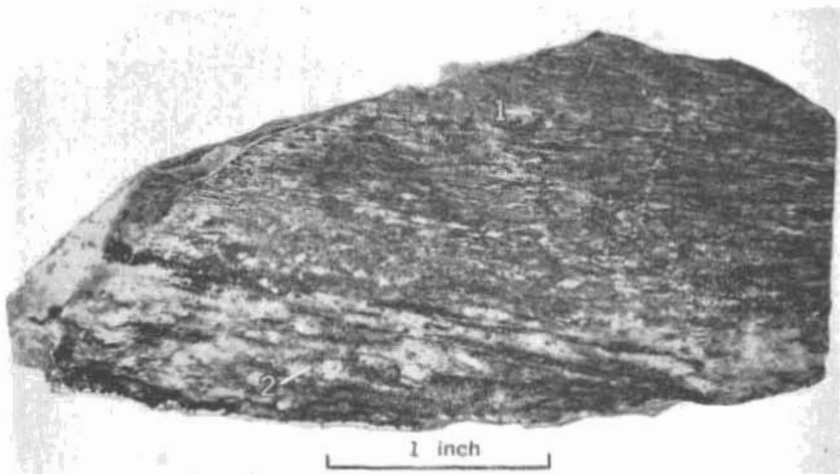

FIGURE 33.—Specimen showing gradation from lime-silicate granulite (1) to hornblende-plagioclase gneiss (2).

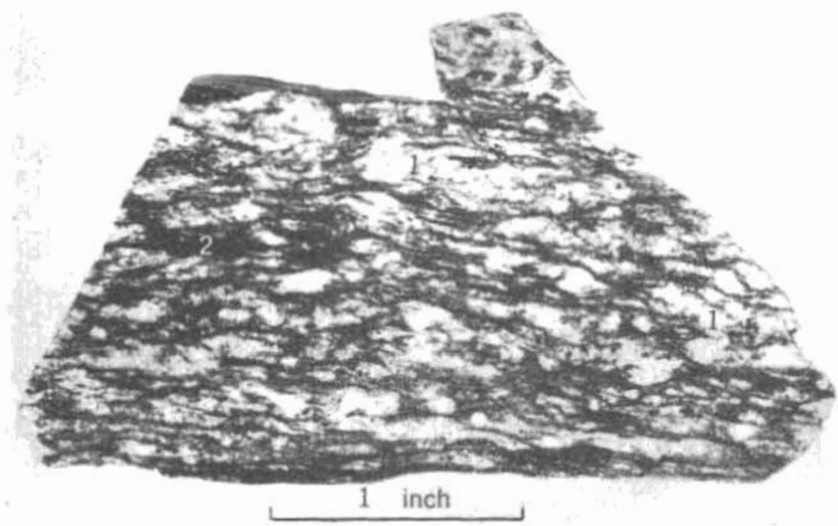

FIGURE 34.—Hornblende-plagioclase gneiss, transitional between granulite and gneissic diorite. Plagioclase porphyroblasts (1), aggregates of granoblastic hornblende (2).

The granulite (specimen 343) is moderately fine-grained and shows well-delineated relict bedding. The texture is granoblastic and hornblende and biotite have replaced some of the augite. The second specimen listed (specimen 344a) includes within a 2-inch section normal to the structure a gradation from finely foliated lime-silicate rock to medium-grained gneissic hornblende-plagioclase rock. The lime-silicate part contains many reddish elongate blebs composed of grossularite and scapolite aggregates. Parallel to these blebs are prominent bands of augite, bordered in places by elongate aggregates of sphene. The third specimen (specimen 344) is representative of a coarse-textured gneissic hornblende-plagioclase rock that has a gradational relationship to the adjacent gneissic diorite, which it closely resembles. For comparison of these specimens, see the photographs of specimens 344a and 344 in figures 33 and 34.

A comparison of granulite and hornblende-plagioclase rock from adjacent beds in an outcrop north of Geikie Glacier indicates the influence of the composition of the original rock on the metamorphic equivalent. The mineral composition of specimens from these two rocks (specimens 149F and 149F2) is given in the following table. The coarse texture of hornblende-plagioclase rock results largely from the size of the hornblende porphyroblasts. The finer grain texture of the granulite (specimen 194F) resulted from the formation of biotite in place of hornblende, which apparently resulted from a surplus of potassium in the original sediment. The texture of the hornblende-plagioclase may be seen in figure 28.

Mineral compositions of granulite and hornblende-plagioclase rock from adjacent bed
[Composition in percent by volume]

Rock name	Specimen No.	Plagioclase [1]	Quartz	Orthoclase	Hornblende	Biotite	Diopside	Prehnite	Chlorite	Sphene	Apatite	Pyrite	Hematite
Granulite	149F	62	------	------	7	24	6.5	1	Tr.	------	------	Tr.	------
Bedded hornblende-plagioclase rock	149F2	50	1	6	27	------	10	------	2	Tr.	Tr.	3	Tr.

[1] An_{35}.

Well-bedded hornblende-plagioclase rock found on the west flank of Blackthorn Peak shows gradation in grain size along the strike of beds as well as between beds. A specimen of this rock (specimen 199) shows pronounced differences within fractions of an inch (see fig. 22). The average mineral composition is: hornblende, 52 percent; plagioclase (An_{32}), 36 percent; diopside, 11 percent; and traces of sphene, apatite, and pyrite. Individual beds are about half an inch thick and range from hornfels to hornblende-plagioclase rock both along and across the strike. The beds of finest grain are of altered plagioclase, the intermediate-grained beds are of poikiloblastic hornblende and diopside and small grains of plagioclase, and the beds of coarsest grain contain large clear crystals of hornblende. This specimen reveals the thinness of the zone that can separate hornfels from hornblende-plagioclase rock. Gradations between the two can be quite abrupt.

PETROGENESIS

The hornblende-plagioclase rock group includes a variety of rocks with the various different rocks representing a corresponding diversity of original rock material and processes of development. Original sources of material probably included igneous flows and sills, and calcareous shale and graywacke. The source rock for a particular hornblende-plagioclase rock can be identified only where relict texture and structure are preserved or where either lateral or normal gradation into a less metamorphosed part of the rock reveals the original type of material.

The similarity in composition between the hornblende-plagioclase rock and some of the possible source rock such as hornfels and granulite indicates that the metamorphic processes involved in its formation could have been largely isochemical.

GRANODIORITE

OCCURRENCE AND DISTRIBUTION

Bodies of granodiorite have been intruded into the diorite and bedded metamorphic rocks of this area in several places. The granodiorite in all of these bodies is similar and forms structureless masses of uniform composition and texture. Where exposed, the contacts of these bodies with the adjacent rock are sharp and denote an intrusive relationship. In places apophyses of granodiorite have penetrated adjacent rocks for as much as several thousand feet. In most places the metamorphic effects of the granodiorite on rock that it intruded are limited to a zone a few feet thick. The most extensive zone of alteration observed was in a sequence of hornfels beds on Threesome Mountain where the intrusion of the granodiorite had brecciated the hornfels and provided many channels for solutions to permeate. Here the brecciated blocks of hornfels had been altered so thoroughly that many appeared as mere shadowy outlines within the granodiorite.

The largest granodiorite stock has an area of more than 10 square miles; it surrounds Abyss Lake and extends about a mile into the area south of Mount Fairweather C-2 quadrangle. The stock is in contact with diorite on all sides except the northeast, where it has intruded thin-bedded red hornfels. Near the middle of the stock, about a mile east of Abyss Lake, a mass of diorite half a mile wide by one mile long remains as a roof pendant capping the granodiorite. A canyon cuts through the center of the stock and exposes it to a depth of 3,300 feet. The canyon is formed by a drainage channel of Brady Glacier via Abyss Lake and its outlet stream. The granodiorite is uniform throughout this vertical distance and forms monolithic walls to the canyon. A widely spaced and notably regular joint system is responsible for the large scale slabby configuration of the cliffs. The uniformity of the granodiorite makes it easy to distinguish from all other rocks in the area.

A second granodiorite stock, located between the crest of Mount Bulky and the terminus of Geikie Glacier, is exposed over an area of about 7 square miles and probably underlies several additional square miles covered by glacial deposits. To the west two bodies of granodiorite, each less than half a mile long, are exposed on the eastern part of the east ridge of Fossil Peak. They may be large offshoots from the Mount Bulky stock.

A third granodiorite stock is exposed over an area of more than half a square mile on the north side of Gullied Peak. As with the other stocks, contacts are sharp and indicate that the granodiorite was intruded into diorite, granulite, and hornblende-plagioclase rock. As the northward extent of this body is concealed by Hugh Miller Inlet the overall size of the stock is unknown.

Small bodies of granodiorite are exposed on several of the islands of Hugh Miller Inlet, along the shore northwest of Hugh Miller Mountain, in the bed of the stream draining northwestward in the valley between Hugh Miller Mountain and Mount Favorite, and in several other scattered places. The similarity of the rock in these small bodies and the larger stocks indicates that they are related and probably were intruded contemporaneously.

The granodiorite in the Geikie Inlet area, because of its similar lithology and its stratigraphic relationships, can be considered as belonging to a granodiorite unit that forms stocks throughout the region to the east and southeast. This granodiorite has been regarded by earlier geologists as being of Cretaceous age.

PETROGRAPHY

The granodiorite is a remarkably uniform rock, composed of approximately 45 percent quartz, 30 percent oligoclase, 23 percent orthoclase, and 1 to 2 percent hornblende and biotite. This low mafic mineral content would justify applying the term leucogranodiorite to the rock. One specimen had a chemical composition as follows: SiO_2, 71.4 percent; Al_2O_3, 15.2 percent; Fe_2O_3, 1.9 percent; MgO, 0.59 percent; CaO, 2.2 percent; Na_2O, 4.2 percent; and K_2O, 3.6 percent. The texture of the granodiorite as seen in thin sections is uniformly hypidiomorphic (fig. 29).

DIKES

FELSIC DIKES

Granitic dikes are distributed sparsely throughout the area and transect every type of rock except granodiorite. Most of these are aplite, but a few are pegmatite. They range from a few inches to 50 feet in thickness and in general have erratic courses. An exception occurs on Contact Peak, where a thick aplite dike cuts vertically through the center of the mountain and crops out as a conspicuous straight white band bisecting the mountain. The aplite dikes and most of the pegmatite dikes are intrusive and probably are genetically related to the granodiorite intrusions. This relationship is demonstrated in the vicinities of both the Gullied Peak stock and the Abyss Lake stock where a large number of aplite dikes penetrate the surrounding country rock.

A specimen of an aplite dike, taken half a mile south of Contact Peak, is composed of about 85 percent of a fine-grained groundmass of partly altered plagioclase and quartz, several altered euhedral crystals of plagioclase (An_{30}), and a hornblende phenocryst now altered to chlorite. Other aplite dikes have a somewhat coarser and more uniform grain size.

A few of the coarse-grained pegmatitic dikes do not affect structures in the host rock and appear to be of replacement origin. Several dikes of this type are exposed in diorite in the bed of Favorite Creek, several hundred feet from Favorite Fiord. The composition is as follows: 40 percent orthoclase, 30 percent plagioclase (An_{35}), 25 percent quartz, 5 percent biotite, and a small amount of magnetite. The texture is xenoblastic. These dikes are too numerous and small to show on the map.

MAFIC DIKES

Mafic dikes are extremely abundant in the limestone and relatively abundant in the other bedded rocks and the diorite. Only one was observed in granodiorite. Individual dikes maintain relatively uniform thickness and follow more regular patterns than the aplite dikes. The thickest dikes observed were about 30 feet thick and the thinnest a few inches thick. From 1 to 3 feet is an average range in thickness.

Most of the mafic dikes are diabasic and have intergranular and ophitic texture. They are composed of labradorite, augite, hornblende, olivine, and magnetite. A dike in the vicinity of Wood Lake, typical of this type of dike, is composed of 55 percent labradorite, 30 percent augite, 5 percent magnetite, and 10 percent olivine that is partly altered to hornblende.

Green to grey porphyritic dikes of mafic rock also crop out in the area but are much less abundant than the lamprophyric dikes. One specimen of a typical green porphyritic dike is composed of phenocrysts of hornblende, a fine groundmass of altered plagioclase grains, and relict phenocrysts of labradorite altered to a fine mosaic of quartz, prehnite, and small plagioclase grains.

A small, irregular dike of mafic rock is exposed on the crest of the south ridge of Fossil Peak. This rock was not observed elsewhere in the area. It is composed of olivine and enstatite with some bastite formed as an alteration of the enstatite.

As with the felsic dikes, these mafic are too numerous and small to show individually on the map.

STRUCTURE

The major structural feature of this area is formed by a belt of bedded rocks that strikes north to N. 20° E. through the central part of the area. On the west side of the belt the beds dip steeply east and on the east side the beds dip less steeply west, suggesting a large and asymmetrical syncline. Stratigraphic evidence for this is lacking, however, as beds are not duplicated on what would be the two limbs of the syncline. Small isoclinal folds are present within the large structure but in general the beds are not distorted very much.

The large structure ends to the north on the ridge north of Maynard Glacier. North of this ridge, in the Gullied Peak area, beds are quite contorted and the structure is complex, if not chaotis. In other parts of the area the structural trend in most of the bedded rocks and the gneissic diorite is parallel to that of the central belt. In a few places such as the Gullied Peak area mentioned above, the structure appears to be chaotic and in other places the strike of the beds is at a large angle to the trend of the central belt. Examples of this latter condition are found on Tlingit Peak where the beds strike east, and on the nunatak northwest of Aurora Glacier where the beds strike northwest.

Structures in the bedded and foliated rocks are truncated by the bodies of granodiorite and in no places do they warp around the granodiorite bodies. This relationship indicates that the deformation of the rocks was complete by the time the granodiorite was intruded. As the granodiorite is presumably of Cretaceous age, the folding is pre-Cretaceous. Inasmuch as late Paleozoic sedimentary rocks are deformed, folding took place after late Paleozoic time. Therefore the orogeny can be dated as probably early Mesozoic or very late Paleozoic.

Throughout southeastern Alaska a system of large faults trending primarily north to northwest has been a controlling factor in the orientation of the many long straight parallel valleys, inlets, and fiords. Within the Geikie Inlet area, a few of the larger and more conspicuous features that are physiographic expressions of this fault system are Favorite Fiord and its extension, Tyndall Cove, Shag Cove, the valley occupied by Geikie and Hugh Miller Glaciers, the transverse valley of Geikie Inlet, and the valley between Mount Favorite and Hugh Miller Mountain. Stream courses are characteristically straight and follow one of the two major fault directions, namely north or northwest. A lesser number flow northeast, normal to the predominant trend. Fault zones in the diorite are commonly colored pink by a coating of laumontite on the fractured surfaces.

Evidence that faulting is taking place at the present time was found on the west slope of Fossil Peak. Here in loosely consolidated talus, a fault scarp with a maximum height of 4 feet extended for about 600 feet along the slope. The upthrown side of the fault was on the downhill side of the slope, so that the scarp formed a sheer wall facing upslope. Streams crossing the fault were dammed by the scarp and were beginning to erode it rapidly. Under these conditions the scarp ridge would not last long and the faulting therefore must have occurred shortly before the scarp was observed, and also must have taken place within a short period of time, probably in one movement. The faulting definitely took place less than 2 years prior to the time of observation, as aerial photographs taken 2 years earlier disclose no trace of the fault.

GLACIAL HISTORY

The glaciers of the Glacier Bay region are highly responsive to slight changes in climate and have undergone several major advances and retreats within the past 8,000 years. During each major advance the valley glaciers have coalesced and formed a central ice sheet that filled most of Glacier Bay. The latest advance reached its maximum in the 18th century at which time the central ice sheet covered an area 54 miles long and from 2 to 12 miles wide, and extended to the mouth of Glacier Bay. In 1794 the front of this ice sheet was clearly visible from Icy Straits (Vancouver, 1798). About the beginning of the 19th century this ice sheet began to recede and by 1879 it had entirely wasted away (Muir, 1895). The valley glaciers that had been tributaries to the main ice sheet continued to recede after withdrawal of the ice sheet, but the retreat of some were obscured by large fields of ice left by the ice sheet in the lower parts of the tributary valleys. Some of this stagnant ice persisted for 50 years even though it lost an average of 20 feet of thickness annually. Once this ice was gone, the termini of the valley glaciers began to retreat up the individual valleys. In the Hugh Miller Inlet and Favorite Fiord areas this disappearance of stagnant ice and subsequent retreat of glacier fronts did not occur until sometime between 1920 and 1930.

Although most of the glaciers in the Glacier Bay region have continued retreating to the present time, several have attained equilibrium since the withdrawal of the ice sheet. In 1912 one of the largest glaciers, Grand Pacific Glacier at the northwest head of Glacier Bay, stopped its retreat and since then has maintained the position of its front within a mile. By 1929 another of the largest glaciers, Johns Hopkins Glacier, had stopped its retreat and in the following 19 years advanced a mile. Most of the other valley glaciers are still retreating. The factor that probably most strongly influences the condition of an individual glacier is the altitude of its basin of accumulation.

The recession of the lower valley glaciers was probably accelerated by changes in the climate resulting from removal of large areas of ice. These changes probably included an increase in prevailing temperatures, a decrease in precipitation, and a decrease in the cloud cover, all of which would adversely affect the glaciers of the region and especially the lower and less stable glaciers.

An excellent record of the retreat of the glaciers during the past 75 years is available from the maps and photographs provided by surveyors and geologists who visited the area at intervals over this span of time. The changes in the glaciers within the area mapped have been extensive and are worth brief descriptions. Inasmuch as these glaciers are continuing to recede, the present conditions will not be maintained for long.

The Hugh Miller, Maynard, Charpentier, and Favorite Glaciers in 1879 apparently all joined a piedmont glacier that was left as a remnant by the main ice sheet. This piedmont glacier filled all of Hugh Miller Inlet, covered about 4 square miles, and was 1,000 feet thick. However, it wasted rapidly; by 1892 it remained attached only to Hugh Miller Glacier, and by 1929 it had vanished. Since then Hugh Miller Glacier has continued to retreat at a rate of 100 feet or more a year and now stands with its terminus a quarter of a mile from tidewater. Its terminus is still a sheer ice cliff instead of the gentle slope common to all other land-bound glaciers in the region.

The other three glaciers that had been joined to the Hugh Miller piedmont glacier continued to join as a single trunk glacier in Charpentier Inlet until sometime between 1906 and 1919 when they separated and each retreated into its own valley. Of these tributary glaciers, Maynard Glacier and the north tongue of Charpentier Glacier are continuing to retreat at present, and Favorite Glacier is now entirely gone. The latter once occupied Favorite Fiord and at one time formed an outlet tongue of Charpentier Glacier that drained into Geikie Inlet. After the ice in Hugh Miller Inlet lowered considerably following withdrawal of the ice sheet, Favorite Glacier reversed itself and flowed toward Hugh Miller Inlet. From then on it was without a source of nourishment and wasted rapidly. In 1919 it still remained hundreds of feet thick and filled a mile of the head end of the fiord, but by 1929 it was gone.

Photographs taken in 1894 show ice fields filling and covering the valley and hills east of Gullied Peak, the entire plateau flanking the northeast side of Red Bed Peak, and much of the valley between Hugh Miller and Favorite Mountains. By 1931 remnants of the latter two still remained (C. W. Wright and F. E. Wright), but in 1950 a small mass of dirt-covered ice 30 feet thick on Red Bed Peak was the last relic of these fields.

In 1879 Geikie Glacier extended far enough down Geikie Inlet for its front to be visible in detail from the entrance to the inlet (Muir, 1895). As Geikie Inlet is 12 miles long, this would indicate that the glacier occupied at least several miles of it. The glacier retreated rapidly from this position so that by 1892 it formed an ice front that encircled the head of the inlet not far off shore from the present shore line (Reid, 1894). By 1906 the ice front was tidal in only a few places and Geikie Glacier was no longer joined on the south to Wood Glacier. In the succeeding years Geikie Glacier continued to retreat so that by 1950 its front stood one and one-half miles inland. At this time it was receding about 200 feet a year and was stagnant up to an altitude of 1,500 feet. As the retreat continues, the coalescing tributary glaciers of the Geikie Glacier system will eventually become separated into individual valley glaciers.

Wood Glacier, once filling the valley now occupied by Wood Lake, probably was part of Geikie Glacier when that glacier was at a maximum stand. Evidence that Wood Glacier flowed through the length of its valley and did not originate locally is found in aerial photographs taken in 1929 which reveal this through flowage by the surface banding. As there was no source of ice to the south, the glacier must have received its nourishment from and actually have been part of Geikie Glacier to the north. By 1892 when Wood Glacier was first observed at close range, it had been cut off from its source of nourishment by the retreat of Geikie Glacier and was a stagnant plateau of ice. As it melted it dammed a large lake on its south side that stood 200 feet above the level of the present lake. The shoreline of this old lake is conspicuously preserved in the valley at present. By 1929 Wood Glacier had been reduced to an ice mass about two-thirds of a mile square, and by 1948 it was gone. Evidence of very extensive glaciation in the area, probably during some earlier advance, was found on the ridge west of Wood Lake about half a mile south of Contact Peak. Striations and chatter marks here indicate that ice flowed over the ridge at an altitude of 2,700 feet heading southward on a bearing of S. 10° W. Also erratic granite boulders strewn on the ridge of Marble Mountain at an altitude of 2,300 feet near the entrance to Geikie Inlet indicate that most of the area described in this report was once covered by ice.

In contrast to the great fluctuation in the glaciers described above, the eastern margin of the south part of Brady Glacier has not attained a level much above the present surface in the past several hundred years. The evidence for this is a well-developed soil mantle not more than 50 feet above the surface of the glacier on the mountains bordering its east side. Standing undisturbed in this soil in many places are the stumps of trees with trunks more than 3 feet in diameter. The development of the soil, the establishment of a conifer forest, the growth of the trees to this large size, the killing of the trees by disease or climate change, and the deterioration of the dead trees to the present stumps would require several centuries without disturbance at a minimum. Therefore in this time the surface of the glacier could not have been more than 50 feet above its present level here.

Each time an ice sheet advanced over the Glacier Bay region, it destroyed or buried forests that had developed during the warmer period preceding the advance. Remnants of such buried forests were found scattered throughout the area. Radiocarbon age determinations of samples from several of these indicate that three and possibly four distinct periods of burial are represented; these ages, corresponding to ice advances, are 300 years ago, 1,500 years ago, 4,000-4,600 years ago, and 7,000 years ago (Bengston, 1955, written communication, and Preston, Person, and Deevey, 1956). These ages correlate well with determinations from fossil forests in other parts of the Glacier Bay region (Lawrence, 1955, written communication). Fossil trees with ages that do not correspond to any of the three periods mentioned above have also been found and may represent additional ice advances.

The fossil trees found in the area were hemlock and spruce, and individual specimens were as much as 3 feet in diameter. In some places groves of trunks are now standing where they have been exhumed recently by streams from the outwash gravel that once buried them. Their tops have been sharply sheared off, indicating that they were partly buried by the gravel before the ice advanced over them and sheared them off at the gravel surface (fig. 35).

ECONOMIC GEOLOGY

No mineral deposits of economic value were found in the area. Many quartz veins were observed over a distance of a quarter of a mile on the north of the ridge immediately south of Charpentier Glacier but these were barren except for large amounts of pyrite. The veins were in limestone and were probably associated with an adjacent body of granodiorite.

Celestite was found along a contact of the diorite and limestone on the 3,493-foot knoll, three quarters of a mile southeast of Fossil Peak summit, but it extended only a few feet along the contact.

A large quantity of dolomite is exposed in the ridge along the west side of Geikie and Hugh Miller Glaciers. Because of its inaccessi-

FIGURE 35.—Trunk of tree that was partly buried about 1,500 years ago by outwash gravels from an advancing ice sheet. At the top of the trunk (a), the fibers are bent and broken where the ice sheared off the part of the tree that stuck above the gravel.

bility it has no economic value at present but when these glaciers melt away, as they are apparently doing, the dolomite will be readily accessible by an easy route from deep water. At this time, which could be within the next 100 years, the dolomite may acquire an economic value.

A Geiger counter with an extra sensitive gamma tube was carried into all parts of the area to determine the presence or absence of large fields of radioactivity. The results were negative.

A magnetic anomaly in the vicinity of the divide of Geikie Glacier immediately west of Blackthorn Peak may indicate a hidden magnetite body. At an elevation of 5,000 feet, or about 2,500 feet above the surface of the ground at this point, the deviation was noticeable. A rough measure by the airplane compass indicated a maximum deviation of 40°.

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