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GEOLOGY AND ORE DEPOSITS

OF

COPPER MOUNTAIN AND KASAAN PENINSULA

ALASKA

BY

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CONTENTS.

ILLUSTRATIONS.

PREFACE.

By Alfred H. Brooks.

This report represents the results of an investigation made in conformity with a general plan to survey in detail the important mining districts of southeastern Alaska. This plan was begun by a detailed geologic survey of the Juneau district, completed in 1903,[1] and is being carried out as rapidly as the funds available will permit. The Copper Mountain and Kasaan Peninsula regions were surveyed in 1907 and 1908; the mineralized belt extending from Juneau to Berners Bay in 1910 and 1911.[2]

Meanwhile geologic reconnaissance surveys and preliminary investigations of mineral resources of all the mining districts of southeastern Alaska have been completed and their results published in several reports. There still remain a number of mining districts which should be surveyed in detail. Such work is very expensive because of the high cost of making the base maps in this region of dense vegetation and excessive rainfall. There is also need of more comprehensive study of the stratigraphy of southeastern Alaska. The mining districts which have been surveyed are regions of very complex structure and of igneous intrusion and metamorphism. Therefore these geologic surveys have been more useful in determining the occurrence of the ore deposits than in elucidating the general structure and stratigraphic sequence in the province. Plans are under consideration for a more exhaustive study of the stratigraphy of this province which it is hoped can be put into execution before long.

In 1909 Mr. Wright left the United States Geological Survey to take up private work in Sardinia, a fact that accounts for the long delay in the completion of this report, which has been prepared at such times as he could spare from his professional work. This delay is regrettable, but meanwhile the interests of the mining industry in this field have not been lost sight of, for the more important economic conclusions and the geologic maps were promptly prepared by Mr. Wright and published.[3] In justice to Mr. Wright it should be stated that he submitted this report in final form in September, 1912, but that a further delay in its publication was caused by the lack of funds for printing.

The descriptions of the developed ore bodies and mine workings here given must be regarded in the main as representing the information at hand up to the close of 1908. Since 1908 important discoveries and developments have been made on some of the properties here described, but these will only in part be referred to in this report. In the early part of 1914 some large operations on copper properties were begun in the Ketchikan district, but the collapse of the copper market led to the suspension of much of this work.

[1] Spencer, A. C., The Juneau gold belt, Alaska: U. S. Geol. Survey Bull. 287, 1906.

[2] Knopf, Adolph, Geology of the Berners Bay region, Alaska: U. S. Geol. Survey Bull. 446, 1911; The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, 1912.

[3] Wright, C. W., Mining in southeastern Alaska: U. S. Geol. Survey Bull. 379, pp. 75-82 and Pls. II and III, 1909.

GEOLOGY AND ORE DEPOSITS OF COPPER MOUNTAIN AND KASAAN PENINSULA, ALASKA.

By Charles W. Wright.

INTRODUCTION.

Location of areas described.—Kasaan Peninsula and Copper Mountain are now (1912) the two most important copper-bearing areas in southeastern Alaska. The first is a peninsula projecting into Clarence Strait from the east side of Prince of Wales Island; the second is a small area which encircles the base of Copper Mountain, on the west side of Prince of Wales Island, and which is readily accessible to ocean traffic by the upper part of Hetta Inlet. Both areas lie within the Ketchikan district or precinct. The town of Ketchikan, which is east of Clarence Strait, is the recording office of the district and an important commercial center.

Scope of report.—It is proposed to consider in detail the geology of Copper Mountain and Kasaan Peninsula. Special attention will be paid to the occurrence of contact ore deposits, which are well exemplified in this region. The mining development will be only briefly described, as it is not of permanent interest and is, moreover, fully treated in the Geological Survey's annual bulletins showing the progress of investigations of the mineral resources of Alaska. The detailed descriptions will be prefaced by a general account of the geology of the Ketchikan district, which is considered essential to an understanding of the details that follow.

Surveys and explorations.—Brief references to the occurrence of copper and other ores in the districts here under consideration appear in some of the earlier publications treating of southeastern Alaska. The first systematic study of this field was made in 1901 by Alfred H. Brooks. The resulting report [1] outlined the general geology of the Ketchikan district and briefly described some of the newly discovered copper deposits of Kasaan Peninsula and Copper Mountain. A more extensive geologic survey of this field was made by F. E. Wright and the writer in 1904 and 1905, and a report [2] on this work described at some length the geology and mineral resources of the Ketchikan district and included brief accounts of the ore deposits of Copper Mountain and Kasaan Peninsula.

All the above work was done without base maps, except the charts delineating the shore line. In 1907 and 1908 D. C. Witherspoon, J. W. Bagley, and R. H. Sargent made a detailed topographic survey of the Kasaan Peninsula.[3] Mr. Sargent made a similar survey of the Copper Mountain region in 1908.[4] These surveys were made on a scale of 1:45,000, and the results have been reduced for publication to a scale of 1:62,500. The contour interval on the map of Kasaan Peninsula is 50 feet, on the map of Copper Mountain 100 feet. The details of relief and drainage are shown with much precision. The mines and prospects are indicated by conventional symbols, as are also the wagon roads and trails.

Geologic study was begun in 1907 by the writer, assisted by Sidney Paige, when a part of the Kasaan Peninsula was covered. The mapping of this area was completed by the writer in

[1] Brooks, A. H., Preliminary report on the Ketchikan mining district, Alaska, with an introductory sketch of the geology of southeastern Alaska: U. S. Geol. Survey Prof. Paper 1, 1902.

[2] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, 1908.

[3] Topography of Kasaan Peninsula, Prince of Wales Island, Alaska: U. S. Geol. Survey Alaska Sheet No. 540B, 1911.

[4] Copper Mountain and vicinity, Prince of Wales Island, Alaska: U. S. Geol. Survey Alaska Sheet No. 540A, 1911.

1908, as was also the geologic work in the Copper Mountain region. A total of six months in two seasons was spent on the work. During this time geologic surveys of about 86 square miles in Kasaan Peninsula and 45 square miles in the Copper Mountain region were made.

Although the preparation of the final report on this work has been long delayed, the geologic maps [1] and the results that bear on the occurrence of mineral deposits were published promptly and will be freely used in this report.

Geologic maps.—The general geologic map of the Ketchikan district (Pl. I) accompanying this report is only slightly modified from one previously published [2] which was prepared by F. E. Wright and the writer.

On the detailed geologic maps (Pl. V, p. 30, and Pl. XV, in pocket) the boundaries of the rock formations, where actually observed in the field, are indicated by solid lines; where only inferred, by broken lines. As outcrops are exceedingly scant in this moss-covered and timber-covered area, the distribution of the formations as indicated on the maps is in large measure only approximately accurate. If a contact between two formations is important in the search for ore bodies its exact position should be determined on the ground by stripping before extensive mining operations are begun.

This report includes a number of maps of mining properties and mine workings which have been furnished by the operators, the geology having been added by the writer.

Acknowledgments.—The field and office work for this report has been done under the direction of Alfred H. Brooks, to whom the writer is indebted for many valuable suggestions. To Fred. E. Wright and particularly to H. E. Merwin, of the Geophysical Laboratory of the Carnegie Institution of Washington, he is indebted for extensive petrographic studies. The stratigraphic and paleontologic studies of E. M. Kindle in this field have also been of great value. In the field work on Kasaan Peninsula in 1907 the writer was ably assisted by Sidney Paige, to whom much credit is due for geologic mapping. To the mine owners, operators, and prospectors of the districts, all of whom extended a hearty cooperation in the work and many personal courtesies, the writer is most grateful. Though impossible to mention all who aided in this investigation, the work was especially facilitated by U. S. Rush, of Kasaan; N. O. Lawton, of Hadley; W. B. Freeburn, of Mount Andrew; and Charles A. Sulzer, of Sulzer. Acknowledgment must also be made to the firm of Winter & Pond, of Juneau, for permission to use certain photographs here reproduced.

KETCHIKAN DISTRICT.

TOPOGRAPHY.

GENERAL FEATURES.

The Ketchikan district includes about 7,200 square miles in the southernmost part of southeastern Alaska. It embraces two distinct topographic provinces, the more rugged being the eastern or mainland belt and the adjacent islands, the largest of which is Revillagigedo, and the other, which has less strong relief, including Prince of Wales and some smaller islands. The coast line of the district is broken by innumerable straits, fiords, and minor indentations. The longest fiord, Portland Canal, which marks the boundary between Alaska and British Columbia, extends about 150 miles inland and is everywhere bounded by steep mountain slopes.

MAINLAND.

The general topographic aspect of the eastern or mainland portion of the Ketchikan district is similar to that of the other portions of the Coast Range province lying on the north and south. The mountains rise abruptly—at some places in sheer cliffs—from tidewater to elevations of 2,000 to 5,000 feet, and the peaks farther inland reach altitudes of 6,000 to 10,000 feet. These mountain masses are for the most part made up of immense batholiths of the granite of the

[1] Wright, C. W., and Paige, Sidney, Copper deposits on Kasaan Peninsula, Prince of Wales Island: U. S. Geol. Survey Bull. 345, pp. 98–115, 1908; also, Wright, C. W., Mining in southeastern Alaska: U. S. Geol. Survey Bull. 379, pp. 67–86, 1909. The geologic maps in this paper form Pl. II (p. 76) and Pl. III (p. 80).

[2] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, Pl. I.

Coast Range, and the land features are chiseled on a corresponding broad scale. Because of the mode of formation and physiographic development of these mountains there is in general a decided lack of bedrock control of the lines of drainage or erosion. Though profoundly dissected, the mountains show a notable tendency to uniformity in the elevation of their crest lines. The summits are generally broad and somewhat flat, and their backs are gently arched so that if the steep-sided valleys were filled to restore their original profiles, the region would present an undulating surface sloping gradually westward from the center of the range.

The form of the land indicates that the region has been intensely glaciated and but slightly modified by water erosion since the glacial epoch. At the time of its maximum extent the ice sheet covered the whole area except some isolated high peaks, which can now be identified by their sharp, serrated outlines—their lack of glacial rounding. Even during the present period of glacial drought a number of small ice fields still exist here in the Coast Range belt, lying above the snow line and sending small tongues down the valleys even to tidewater. The region contains abundant and striking features of glacial sculpture, such as U-shaped valleys, fiords, glacial erratics, cirques, hanging valleys, double-cliff slopes, truncated spurs, alignment of cliff bases, and glacial grooves and striæ. The notable absence of moraines in this area of extensive glaciation is due chiefly to the steepness of the slopes of the mountains and valleys. Many of the fiords are floored with sand and gravel moraines, and some of them are partly choked at their entrances by morainic material. Forelands occur here and there, but they are small, and the region includes no large areas of level land. The peninsulas and the adjacent islands are more or less separated from the mainland by deep, narrow fiords extending many miles inland and they contain mountains whose summits range in height from 2,000 to 4,000 feet above sea level.

The mainland belt is intricately dissected by narrow, steep-sided valleys heading in canyons, many of which are filled with snow, or in glacial cirques, a number of which contain small glaciers or patches of ice. The initial descent of these valleys is steep, the streams in places forming beautiful waterfalls of considerable volume. Farther down the slopes tributary creeks or rivers enter these streams from both sides, the valleys gradually widen, and the valley floors become covered with a gravel wash consisting largely of gravel, cobbles, and bowlders of granite. As the grade decreases the gravel beds become deeper and wider, and the stream flows around the flanks of precipitous mountain spurs and enters the sea at the head of some tidewater inlet. The tidal flats at these points are usually wide and are composed of deep fine sand and mud, the depth to bedrock being probably several hundred feet. They extend into the channels for a short distance beyond the low-tide line and there end abruptly. Depths of 50 to 100 fathoms are common in these inlets a short distance from the shore.

The seaward extension of many of these valleys is represented by tidewater channels or fiords. The largest of these in this region is Portland Canal, which penetrates the mainland for some 150 miles, with an easterly and then a northerly course. From its sides the mountains close at hand rise to elevations of 4,000 to 6,000 feet. Bear and Salmon rivers discharge into the head of this canal.

PRINCE OF WALES ISLAND.

There are no topographic maps of Prince of Wales Island, and little is known in detail of the courses of its valleys or of its mountain ranges. Its eastern shore line has been charted by the Coast and Geodetic Survey, but the mapping of the western coast is still incomplete.

Prince of Wales Island is 80 miles long and 30 miles wide, and is separated from the mainland by Clarence Strait, a deep channel 5 to 10 miles wide, trending about north and south. Its shore line is indented by numerous bays and inlets, which are characteristic of the entire coast. Portions of its west coast are directly exposed to the Pacific Ocean, but most of it is protected by small seaward islands, the largest of which is Dall Island. Viewed from the channels Prince of Wales Island presents a mountainous mass of very irregular outline. Its relief, however, is less rugged than that of the mainland or of some of the islands to the north, such as Baranof Island. A low pass across the island, 4 miles long and less than 150 feet high, connects the head of Cholmondeley Sound on the east coast with the head of Hetta Inlet on the west coast.

Another pass, 6 miles long, unites the south arm of Cholmondeley Sound with Klakas Inlet. The head of Twelvemile Arm also is connected with Big Harbor on the west coast by a portage several miles long. There are also probably other low gaps between the east and west coasts of the island. Numerous lakes occur on the island both in low-lying valleys and in basins lying at elevations of 1,000 to 2,000 feet. The mountain summits range in height from 2,000 to over 3,000 feet, one of the highest being Copper Mountain, 3,900 feet above sea level.

In general both the course of the valleys and the trend of the small mountain ranges of this island conform to the underlying rock structure, which has largely controlled the erosive processes. The intrusive masses and limestones usually persist above the general level and form the hills, ridges, and mountain peaks. The areas of shales, sandstones, and other less resistant rocks are marked by lowlands, deep valleys, and channels.

There are now no glaciers on Prince of Wales Island, but evidence of former glaciation is everywhere present. Basins scooped out by glacial action and now filled with lakes occur at elevations of a few hundred to 2,000 feet in the vicinity of Copper Mountain, and the surrounding mountains, composed essentially of granite, are well rounded and bear many large bowlders that are evidently erratics. In the Klawak Range, farther north, there are several clearly defined glacial cirques containing small lakes and surrounded by more or less jagged crest lines. Grooves observed at a few places on rocks exposed along the tidewater channels may also be attributed to glaciation.

The coast line of this and adjacent islands is broken by bays, coves, and channels. The charts of this area show numerous excellent harbors and many protected channels that favor navigation. One of the striking features is the shallowness of many of the bays and channels as compared with the depths noted in the fiords of the mainland belt. Again, the river deposits at the heads of bays have a gradual slope; they do not descend abruptly into deep water a short distance from the shore, as do the tidal flats along the mainland. These facts and the topographic observations tend to show the greater advance in topographic development of the seaward part of the region in contrast with that of the mainland.

CLIMATE.

The annual changes in climatic conditions in southeastern Alaska are not so varied as might be expected in a region lying between 55° and 60° north latitude. The effect of the warm waters of the northern Pacific is strongly felt and serves to moderate the climate. The region is characterized by mild winters and cool summers. The mean annual temperature is about 45° F. The mean temperature of the three summer months is about 55° F.; of the three winter months about 35° F. The precipitation is heavy and is greatest where high mountains abut on the sea. Nearly all the precipitation below an elevation of 500 feet is in the form of rain. Rainfall records in the Ketchikan district are scant, but indicate a total precipitation of about 98 inches at Shakan, near the north end of Prince of Wales Island, and of 148 inches at the town of Ketchikan. Most of the rain falls between the first of September and the last of January, though the amount varies greatly from year to year. The season of least rainfall is generally from April to July. The snowfall is heavy in the mountains, from 3 to 8 feet in depth, but near sea level not more than a few inches of snow falls at one time during an ordinary winter, and this soon disappears.

The prevailing winds come from the southwest and bear moisture from the sea, which condenses in the form of fog and rain about the mountain range. The abundant precipitation is trying to those who are accustomed to a more arid climate, but this rainfall, though a drawback to the prospector, does not interfere with mining development. It is an advantage, for it furnishes water power which can be utilized in mining operations.[1] Except at high altitudes snow does not interfere materially with transportation or mining.

[1] Hoyt, J. C., A water-power reconnaissance in southeastern Alaska: U. S. Geol. Survey Bull. 442, pp. 147-157, 1910.

VEGETATION.

The growth of timber and vegetation along the coast of southeastern Alaska is almost as dense as that of a tropical region. Its luxuriance is caused by the moist and temperate climate and the long summer days of this latitude. At elevations below 1,500 feet bushes, ferns, and tall grasses grow profusely, especially in the valleys and gulches. In places these form a dense and almost impassable undergrowth and are a great hindrance to the prospector. The timber is almost entirely of coniferous species, principally western hemlock and spruce, and is in general of an inferior grade, suitable only for rough work. The timber line ranges in elevation from 1,500 to 2,500 feet, but most of the large trees grow at low altitudes. The stands of commercial timber vary greatly, ranging from 30,000 to 80,000 feet (board measure) per acre. The average run of saw timber in southeastern Alaska, however, because of the scant growth in the swamps and on the higher slopes, is not more than 5,000 to 10,000 feet per acre.

The hemlock is used for piling, but most of the lumber cut in the local sawmills is spruce. The cedar is not sufficiently abundant to have much value. The entire Ketchikan district lies in the Tongass National Forest.

There are some good agricultural lands in the flats, but they are of small extent. Some of them have been successfully utilized for gardening, for which use the climate and soil are favorable.

COMMERCIAL CONDITIONS.

Ketchikan, the prosperous commercial center of the district, is on the west side of Revillagigedo Island, which lies close to the mainland about 15 miles east of Prince of Wales Island. It has a population of about 1,500 and is provided with all necessary municipal improvements. It is an important fishing center and has ample wharves, good hotels, banks, and stores. It is connected by cable with Seattle and with Alaska ports. Supplies can be purchased at little advance over Seattle prices. Coal is brought from Vancouver Island and retails at about $8 a ton (1908).

Communication is maintained between the mining camps and Ketchikan by steamships and launches. Ketchikan is 52 hours from Seattle by steamships following the inside passage, three to five entering the port every week from the States. Direct weekly steamship connection is also maintained with Vancouver, British Columbia. Prince Rupert, the western terminal of the Grand Trunk Pacific Railway, to be completed in 1915, is only 5 hours by steamer from Ketchikan.

The timber supply of the region is adequate for all mining purposes. The local sawmills furnish rough lumber, and good timber for piling is abundant. There are also some good water powers in the district, though they are but little developed. The irregular coast line affords many good harbors, which are free of ice throughout the year. As a general rule the country is one of strong relief, which is favorable to mining developments through adit tunnels and without hoisting.

The conditions in general in the district are exceptionally favorable to mining operations and, except for the irregularity of some of the ore bodies, are almost ideal for reducing operating costs to a minimum.

PRODUCTION OF COPPER.

The occurrence of copper deposits on Kasaan Peninsula was known even during the Russian occupation, but small heed has been paid to them except in very recent years. An attempt was made to establish a copper-mining industry near the present site of Kasaan in 1879–80, but it was abandoned after a few tons of ore had been mined and shipped. The copper now produced in the Ketchikan district is derived almost entirely from mines on Kasaan Peninsula and about Copper Mountain. The growth of the copper-mining industry in this field is shown in the following table:

Ore production from copper mines in the Ketchikan district, 1905–1911.

Year.	Ore mined.	Copper.		Gold.		Silver.		Average value of ore per ton.
		Amount.	Value.	Amount.	Value.	Amount.	Value.	
	Tons.	*Pounds.*		*Ounces.*		*Ounces.*		
1905	30,400	1,901,392	$295,616	1,178	$34,370	13,000	$7,867	$10.79
1906	85,139	4,350,571	838,660	3,031	62,851	27,152	18,102	10.81
1907	79,982	4,758,814	951,761	3,384	69,960	44,196	29,143	13.14
1908	43,215	3,260,399	430,372	2,213	46,310	24,648	13,063	11.10
1909	28,491	2,705,988	351,778	1,946	40,228	16,679	8,641	14.06
1910	27,425	2,254,487	286,320	1,503	31,081	14,598	7,884	11.86
1911	13,753	977,468	120,719	613	12,678	6,573	3,484	9.95
1912	13,494	1,234,888	203,756	1,080	22,335	10,035	6,171	17.21
1913	7,276	599,903	92,985	484	10,000	4,447	2,686	14.52
	329,175	22,043,900	3,571,967	15,432	329,813	161,328	97,041	12.15

The copper production of the district previous to 1905 is estimated at 1,600,000 pounds. At 12 cents a pound, the average price of copper for the period in which it was mined, the value of this output is $192,000. These amounts, added to those for 1905 to 1913, give a total copper production of 23,643,900 pounds and a total value of $3,763,967.

Practically the first large shipments of ore were made in the spring of 1905. The rise in the price of copper from an average of $0.156 a pound in 1905 to an average of $0.20 a pound in 1907 permitted the profitable extraction of copper ores of low grade averaging 59 pounds per ton, and with the improvements in methods of transportation and mining the production was much increased. In 1908 the average price of copper dropped to $0.132, and this led to the closing down of some of the principal producing mines. Of ten producing mines in 1907 only five were operated in 1908 and only three or four during the following years. From these the average copper content per ton of the ore shipped was about 90 pounds. In 1911 only three mines were producing, and the ore shipped yielded on an average 70 pounds of copper per ton.

GEOLOGY.

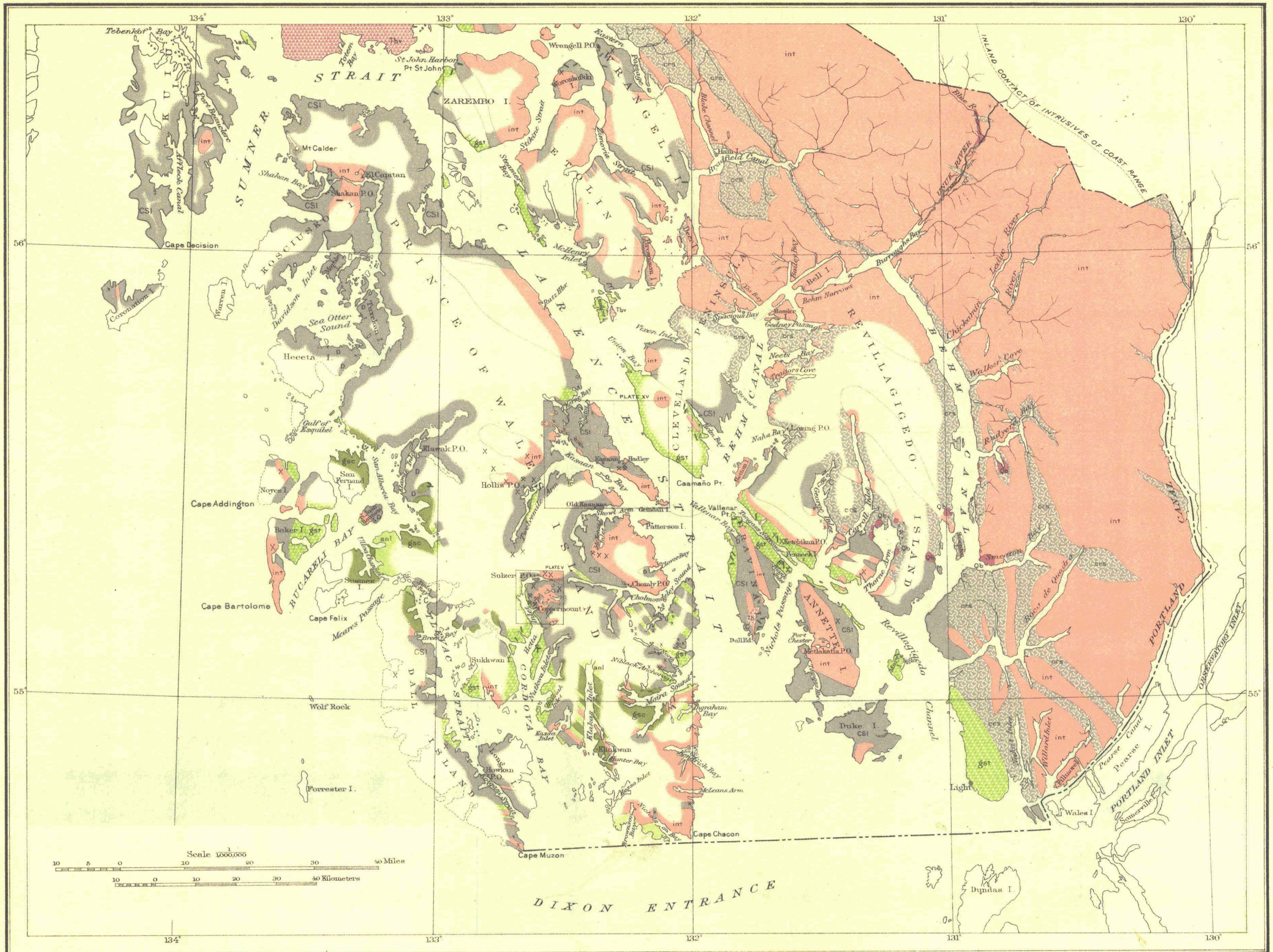
GENERAL FEATURES.

The geology of the Ketchikan district is but imperfectly known, for, except in the two areas to be described in detail below, observations have been confined almost entirely to the shore lines, and this limitation, together with the gaps in the information regarding continuity of formations and stratigraphic relations caused by the many broad waterways, has prevented the exact determination of either stratigraphic sequence or structure. Hence the sedimentary rocks of the region, which range in age from Silurian to Jurassic or Cretaceous, will be described in only a general way, but as the knowledge of the igneous rocks is more exact and comprehensive, these will be described in greater detail.

The geologic map (Pl. I) shows that the intrusives of the Coast Range occupy a larger area than any other of the rock units that have been discriminated. The main batholiths of these intrusives occupy the eastern part of the district and form a convenient starting point for a geologic description, though they by no means represent the oldest rocks of the district. Adjacent to these intrusives on the west and in part included within their area lies a series of crystalline schists which, though in places showing igneous phases, are for the most part sedimentary. The seaward and western boundaries of these schists are marked by a belt of argillites—either slates or phyllites—in part interbedded, in part succeeded by ancient lavas and tufts that are here grouped together as greenstones. Some semicrystalline limestone bands occur in this slate and greenstone series, and as Carboniferous fossils have been found in these limestones the entire sequence has heretofore been referred to the Carboniferous period. This determination of the age of the series accords with Spencer's [1] provisional determination of the age of similar rocks that apparently represent a northern extension of the same belt. Knopf's [2]

[1] Spencer, A. C., The Juneau gold belt, Alaska: U. S. Geol. Survey Bull. 287, p. 17, 1906.

[2] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, pp. 17-18, 1912.



LEGEND

QUATERNARY
Recent
- Qb — Basaltic lava

TERTIARY
Eocene
- Tbv — Basaltic lava flows interstratified with volcanic tuffs and breccia
- Tc — Conglomerates, sandstones, shales, and coal seams

MESOZOIC
Jurassic or Cretaceous
- gsc — Graywackes, slates, and conglomerates containing granite pebbles
- anl — Andesitic lava flows interstratified with volcanic tuffs, conglomerates, and graywackes
- d — Dikes, including diabase, andesite porphyry, and felsite
- int — Intrusives of Coast Range, including granite, granodiorite, diorite, and peridotite

PALEOZOIC
- gst — Greenstone lava flows interstratified with volcanic tuffs and black slate
- crs — Crystalline schists
- CSl — Carboniferous limestones, slates, schists, conglomerates, and volcanic tuffs; Devonian limestones, schists, sandstones, and conglomerates; Silurian limestones, cherts, and quartzites

- ⚒ — Mine
- X — Prospect
- C — Localities of Carboniferous fossils
- D — Localities of Devonian fossils

GEOLOGIC RECONNAISSANCE MAP OF THE KETCHIKAN AND WRANGELL MINING DISTRICTS, SOUTHEASTERN ALASKA

By F. E. and C. W. Wright

1914

Base compiled chiefly from charts of U. S. Coast and Geodetic Survey recent studies north of Juneau have shown, however, that these rocks are in part, at least, of Jurassic or Lower Cretaceous age. This series of slates, phyllites, schists, and greenstones may therefore be Mesozoic, though it may include some infolded Carboniferous limestones. On the map the sedimentary rocks adjacent to the Coast Range are not differentiated from the sedimentary rocks that lie farther west, most of which are older than those near the Coast Range.

But few correlations have been made between the rocks of Prince of Wales and adjacent islands and those of the mainland belt described above. Igneous rocks like those found in the Coast Range occur as intrusives in this western province. Some of the sedimentary rocks here are also lithologically the same as some of those found farther east, and the likeness suggests certain correlations which can not yet be definitely established. The sedimentary rocks of Prince of Wales Island include slates, quartzites, arkoses, and conglomerates, and locally a large amount of limestone. The fossils found in these rocks indicate the presence of strata ranging in age from Silurian to Carboniferous. The rocks of the island include also a series of volcanic deposits and another of graywackes and conglomerates, which on stratigraphic grounds have been assigned to the Mesozoic. The Paleozoic formations have not been differentiated on the geologic map (Pl. I), which therefore indicates a sameness in the geology of Prince of Wales Island that is by no means in accord with the facts. The continuity along strike lines that is characteristic of the mainland does not prevail on Prince of Wales Island, where the rocks show close folding, which, with the presence of many large stocks of igneous rocks, has given great variety to the geology. The Tertiary period is represented in the district by one small area of conglomerate, sandstone, and shale; the Quaternary by many widely distributed basaltic lava flows, though none of any great areal extent.

Of the igneous rocks the intrusives of the Coast Range, made up of granite, diorite, granodiorite, and peridotite, are most abundant and most widely distributed. These are believed to be of Mesozoic age. Dikes of diabase, porphyrite, and felsite are widely distributed and are probably later intrusives.

SEDIMENTARY ROCKS.

PALEOZOIC STRATA.

Little or nothing is known of the oldest rock formations in the district, but it is doubtful whether they include pre-Paleozoic strata. The crystalline schists and gneissoid rocks, which form a wide band adjacent to the Coast Range and resemble the ancient metamorphic clastics of other regions, are mostly of late Paleozoic and early Mesozoic age, and their present crystalline condition is attributed to metamorphism caused in part by the intrusives of the Coast Range.

The sedimentary record begins with the Silurian, which is represented by fossiliferous limestones. These limestones include thick strata of banded graywacke, and the limestone and graywacke together form a belt that is exposed at points on the west coast of Prince of Wales Island and on Kasaan Peninsula. The banded graywackes are nearly everywhere extremely fine-grained or aphanitic, indurated, clastic rocks, gray to green in color, very brittle, with little or no cleavage. They include both sedimentary strata and indurated beds of tuff with mixed sedimentary material. Weathering usually produces a brown surface by the oxidation of pyrite and other ferruginous particles. The total thickness of the beds can not be estimated because of complicated folding, though it must amount to many thousand feet.

At the base of the Devonian lie thick beds of conglomerate containing pebbles and cobbles derived from the older Silurian beds, and indicating that an unconformity occurs between the Silurian and Devonian strata, though the rocks of these two periods were not observed in contact.

At many places along the northwest shore of Prince of Wales Island and on the smaller islands adjacent to Davidson Inlet a thick series of limestones overlies these beds of conglomerate, and together the two series represent the lowest horizon of the Devonian system. The conglomerates consist essentially of cobbles of banded quartzite and some fragments of limestone and schist. Toward the limestone beds they grade into sandstone and slaty limestone. They are conformably overlain by the limestones. Narrow beds of the sandstone are also interstratified with the beds of limestone. The limestones are semicrystalline and gray to blue in color, and not many of the fossils in them are identifiable. At several points, however, imperfect fossils, which have been referred to the Devonian, were gathered, the largest collection having been obtained on the east shore of Haceta Island, from beds directly overlying the conglomerates.

The total thickness of the conglomerate beds is estimated at 1,200 feet and that of the overlying limestone beds at 1,800 feet. At this locality the strata are broadly folded and the rocks are considerably metamorphosed.

A somewhat higher horizon of the Devonian is represented by the limestone beds on Long Island, in Kasaan Bay, on the east side of Prince of Wales Island. At this locality both Lower and Middle Devonian faunas have been recognized, though the limestone strata containing them are apparently conformable.

The stratigraphic relations of the limestones of Long Island to the beds on the adjacent shore of Kasaan Bay can not be definitely determined because of their topographic isolation.

The Middle Devonian horizon occurs again about 20 miles south of Long Island, at the head of Clover Bay, where there is a small area of schistose argillites and black limestone almost completely surrounded by an intrusive mass of diorite. These beds are highly tilted and have a general easterly strike.

At Vallenar Bay, on the north end of Gravina Island, beds of shaly limestone, argillaceous schist, and schistose conglomerate containing a Middle Devonian fauna occupy the crest of an anticline. These beds underlie the slates and greenstones which border the east and west shores of the island. The Devonian beds at this locality and those on Long Island were included under the name Vallenar series by Brooks in his report on the Ketchikan district.[1]

Limestone beds containing an Upper Devonian fauna and overlying with apparent conformity banded argillaceous beds, similar to those of Middle Devonian age exposed at Clover Bay, occur on San Juan Bautista Island and in Klawak Inlet, on the west coast of Prince of Wales Island.

The distinctions between the three divisions of the Devonian—the Upper, Middle, and Lower—in most places are not clearly defined paleontologically, and at no locality was a complete section of these horizons obtained.

The stratigraphic relations between the early Carboniferous and the late Devonian formations are not definitely known, and in no place were the formations observed together. The early Carboniferous is represented by fossil-bearing limestones on an islet at the entrance to Soda Springs Bay, on the west coast of Prince of Wales Island. The limestone beds strike north and are steeply tilted toward the east. They overlie with apparent unconformity conglomerates and sandstones that resemble those of early Devonian age. On Prince of Wales Island opposite this islet there are slates and chlorite schists which resemble those probably belonging to the slate and greenstone series of Copper Mountain.

Fossils were found in beds of calcareous shale that outcrop on the south end of Gravina Island, 3 miles north of Dall Head. These fossils were fragmentary and could not be definitely determined, but are provisionally referred to the early Carboniferous. They may, however, represent a Triassic horizon.

Few data exist concerning the interval between the early and late Carboniferous faunas, as the rocks containing the two faunas are nowhere present at the same locality and no fauna representing the intervening epoch has been found. The upper Carboniferous, which probably includes the most extensively developed formations, is represented by fossiliferous limestone beds at George Inlet, within the mainland belt, and at several points on the islands. In the mainland belt the limestones are included in a succession of argillites and crystalline schists, which are closely folded and highly metamorphosed and form a band about 10 miles wide

[1] Brooks, A. H., Preliminary report on the Ketchikan mining district, Alaska: U. S. Geol. Survey Prof. Paper 1, pp. 42-43, 1902.

adjacent to the intrusives of the Coast Range. These metamorphic strata, called by Brooks [1] the Ketchikan series in this province, probably include several formations, which, however, have not been defined because of the complexity of their structure and the extent of their metamorphism. They probably include formations as old as the Carboniferous and as young as the Jurassic (see p. 16), but the subdivisions have not yet been differentiated. Similar rocks are widely distributed, not only on the mainland and adjacent islands but on the west coast of Prince of Wales Island.

The most recent of these metamorphic rocks are the greenstone lava and tuff beds interstratified with beds of black slate. The structural relations of these beds to the older and younger rocks indicate that they are upper Carboniferous or Mesozoic, as they overlie the limestones (Carboniferous) and schists with apparent conformity. Similar rocks in the Juneau district were described by Spencer [2] as the "slate-greenstone band." Knopf's recent work has shown that these sediments in the Juneau district are probably of Jurassic age and has correlated them with the Berners formation, made up of slates, graywacke, and some greenstones.[3]

The greenstone and slate series of the Ketchikan district trend in many places parallel to the older limestones and schists, although they exhibit many local variations in strike and dip. Their total thickness is estimated to be over 4,000 feet. They occur principally along the outer border of the mainland belt in Tongass Narrows and on Cleveland Peninsula, but they also form a smaller belt along the west coast of Prince of Wales Island.

As a whole, the greenstone members of this slate and greenstone series predominate over the slate or the sedimentary beds, but the relative proportion varies from place to place, presumably because of inequality in the distribution of the lava flows and tuffs. The igneous and sedimentary material in these beds is intimately associated in varying amounts and grades from altered andesitic lavas and tuffs to purely sedimentary beds.

MESOZOIC STRATA.

The formations in the Ketchikan district that have been referred to the Mesozoic era contain no fossils, and the determination of their age is therefore based entirely on their structural and petrographic features. The possible Mesozoic age of the slate and greenstone series has just been indicated.

So far as known, the intrusives of the Coast Range, which occupy about half the land area of southeastern Alaska, invaded the bedded formations early in the Mesozoic era. These intrusives are discussed under the heading "Igneous rocks" (p. 20).

At the south end of Prince of Wales Island there is a series of andesitic flows, conglomerates, and tuffs, which grade into a series of graywackes or indurated sandstones, including some beds of slate. These rocks have been considered Mesozoic because of their structural and petrographic relations to the older rocks. In this series basaltic and andesitic flows are intercalated with tuffaceous beds, and both flows and tuffs alternate with the sedimentary slates, graywackes, and conglomerates. The rocks of the series are readily distinguished from the greenstones by the wide difference in the composition and texture of the interstratified beds and by their predominant reddish color. A fine, compact green tuff is usually overlain by an andesitic lava containing numerous large plagioclase phenocrysts, which is in turn overlain by a basaltic lava or a red lava conglomerate. The greenstone beds, on the other hand, vary little in composition and, where massive, augite crystals form the phenocrysts.

On the south end of Prince of Wales Island the andesitic flows and conglomerates overlie at several points the eroded surfaces of granitic intrusive masses, and numerous dikes of the andesite intrude these older granites. Pebbles and fragmentary masses of the granite were observed in the tuffaceous conglomerates, showing clearly that the andesites are younger than these masses of granite rock. The granites at this point were more altered and contained more shearing planes than are generally found in the intrusives of the Coast Range, and they may

[1] Brooks, A. H., op. cit., pp. 44-45.
[2] Spencer, A. C., op. cit., pp. 16-17.
[3] Knopf, Adolph, The Eagle River region, southeastern Alaska: U. S. Geol. Survey Bull. 502, pp. 13-14, 1912.

represent a batholith intruded before or during the earliest stages of the granitic invasion of that range. The graywackes overlying the andesites are compact and indurated but show no schistosity. Pebbles of granodiorite, quartz, andesite, and graywacke are plentiful in the conglomerates. These beds as a whole, though tilted at steep angles and folded, have not suffered the intricate folding and metamorphism seen in the older rock beds, including those of the Sitka district. No fossils were found in these beds, but the facts above stated indicate that they occupy a position in the stratigraphic column between the Triassic and the Upper Cretaceous. It is possible that their horizon may be the same as that of the slate and greenstone found adjacent to the Coast Range batholith. (See p. 16.)

TERTIARY STRATA.

Tertiary beds are widely distributed along the Pacific seaboard of Alaska, though their total areal extent is comparatively small. In the Ketchikan district they are found only on Prince of Wales Island, where they occupy a small basin at Coal Bay, a southern arm of Kasaan Bay.

The Tertiary rocks comprise conglomerates, sandstones, and impure lignitic coal seams. They are soft, friable, and unmetamorphosed. There are very few exposures of these rocks, but judging from the better-developed Tertiary beds to the north they are probably but little disturbed.

RECENT DEPOSITS.

The few Recent deposits in the districts under discussion consist of stream gravels covering narrow valley bottoms and somewhat more extensive deposits at mouths of deltas. Some stream terraces noted on Kasaan Peninsula are probably underlain by gravels. Most of the beaches are rocky, consisting generally of almost shear cliffs, but locally some small sand and gravel beaches have been developed. In places in tidal flats there are also some more extensive deposits of fine alluvium. Glacial deposits of various types also occur in the Ketchikan district. None of these Recent deposits is indicated on the accompanying geologic maps.

IGNEOUS ROCKS.

CLASSES DISCRIMINATED.

The igneous rocks include (1) the intrusive masses, such as the dioritic and granitic batholiths, gabbros, and peridotites which invade the sedimentary rock beds; and (2) the extrusives, or those which represent surface lava flows, such as the greenstones, andesites, and basalts. The most abundant and important of the igneous rocks are the granitic intrusives of the Coast Range, which occupy about one-half of the aggregate land area of the district.

INTRUSIVES OF THE COAST RANGE.

GENERAL FEATURES.

The Coast Range massif as it has been defined by Dawson is not of the same composition throughout, but is composed of different kinds of igneous rocks, ranging from granite to diorite. The most noteworthy feature of the entire Coast Range mass of intrusives is their general uniformity in texture and their continuity. The variations across the range are apparently not so gradual as those along its trend. The Coast Range massif consists of many separate interlocking batholiths, or batholiths within batholiths, intruded at successive epochs but during the same general period of irruption.

The petrographic field term "granite," which has been generally used to designate these intrusives, applies to only a small part of the rocks, the prevalent type being a quartz hornblende diorite, though gradations to granodiorite, diorite, and gabbro, with hornblende and biotite as colored constituents and titanite as a frequent visible accessory, are common. As a general rule hornblende appears to be more abundant near the coast, while biotite predominates near the inland border of the Coast Range batholiths.

Although the composition of the batholiths varies considerably from point to point, it is desirable to ascertain the approximate average composition of the entire mass. To this end seven typical specimens were selected from different parts of the range. These specimens were chosen with special regard to their abundance and general distribution throughout the area, abnormal and rare types being disregarded altogether. Each of these specimens was studied in detail under the microscope, and a careful estimate of the relative quantity of each mineral in the rock was made from the thin sections by the Rosiwal method. Although the values thus obtained are only approximate, they represent roughly the general mineral content of the batholiths.

The following average mineral composition was thus obtained:

Average mineral composition of the intrusives of the Coast Range.

Quartz	19.4
Orthoclase	6.6
Andesine ($Ab_{56}An_{44}$)	47.4
Hornblende	7.6
Biotite	11.6
Apatite	.6
Magnetite	.9
Pyrite	.1
Titanite	1.3
Epidote	3.5
Chlorite	.1
Calcite	.1
Kaolin and muscovite	.8
	100.0

The average specific gravity, 2.77, was determined by weighing the hand specimens in air and then in water.

From these data the average chemical composition was calculated by assuming for the hornblende and biotite the compositions of like minerals from a similar rock from Butte, Mont.

Average chemical composition, norm, and classification of the intrusives of the Coast Range.

Average chemical composition.			Norm.				Classification.
Constituent.	Per cent.	Molecular ratio.					
SiO_2	61.0	1.017	Q	16.14	16.14	84.26	Class, $\frac{Sal}{Fem}=4.78$
TiO_2	1.0	.013	Or	13.32	68.12		Order, $\frac{F}{Q}=4.22$
Al_2O_3	17.5	.171	Ab	27.78			Rang, $\frac{K_2O'+Na_2O'}{CaO'}=0.82$
Fe_2O_3	1.6	.010	An	27.02			Subrang, $\frac{K_2O'}{Na_2O'}=0.45$
FeO	2.7	.038	Di	4.81	10.56	15.52	
MnO	.1	.001	Hy	5.75			
MgO	2.4	.060	Mt	2.32	4.29		
CaO	6.9	.123	Il	1.97			
Na_2O	3.3	.053	Ap	.67	.67		
K_2O	2.3	.024					
H_2O	.9	.050					
P_2O_5	.3	.002					
	100.0						

Its chemical and mineral composition places this rock in the family of quartz diorites, of the type tonalite, according to the usual classification. In the quantitative classification of Cross, Iddings, Pirsson, and Washington the rock is dosalic, dosalone, quardofelic, alkalicalcic, and dosodic, and belongs in Class II, order 4 (austrare), rang 3 (tonalase), and subrang 4 (tonalose). In short, it is tonalose of the ordinary type.

The amount of titanite is unusually large, as it is in many of the intrusives of the Coast Range. The hornblende occurs usually in dark prismatic crystals, noticeable for excellent prismatic cleavage and lack of terminal faces. Many biotite flakes are hexagonal and deep brown in transmitted light. A few crystals of apatite are visible to the unaided eye, but this mineral occurs generally in fine hexagonal microscopic crystals. Pale-green veinlets of secondary epidote, which follow fracture planes in the granodiorite, are not rare.

These even-grained rocks generally have the normal, sharply defined, granitoid texture, but include also gradations to holocrystalline porphyritic phases, due to the superior development of the feldspars. Gneissic structure is common near the western margin of the Coast Range belt. In some places gneissic structure has been so far developed in the granite and the neighboring invaded sediments have been so thoroughly converted to gneiss that it is difficult to define the precise limits of the original intrusive granite.

CONTACT FEATURES.

The granite near the contact contains abundant inclusions of the intruded schist. These inclusions become more and more coarsely crystalline away from the contact, until finally they resemble basic or acidic differentiation products and are gradually lost to sight. Pegmatite and aplite dikes form an intricate network and mesh of white strands along the outer portions of the granodiorite massifs and in the adjacent schists, but are practically absent in the central parts of the batholiths. Several systems of such dikes were observed. The oldest set occurs as thin narrow bands following master joint planes and standing out as ribs above the surface of the more easily weathered granite; a second set is wider and usually perpendicular to the first; and a third and still later set, which is distinctly irregular, apparently fills the largest fracture cracks. This condition suggests that during the last period of magmatic activity the rock masses underwent considerable movement and fracturing and were brought nearer the surface. That still later differential movement has taken place is evident from the minor faulting of the pegmatite dikes themselves. At a distance this schist complex, with its innumerable pegmatitic dikes, resembles a breccia, the white pegmatites acting as interstitial cement for the dark angular fragments and blocks of schists. The occurrence of these innumerable pegmatites in the schists along the margin of the Coast Range batholiths is a significant indication of the immense quantities of pneumatolytic solutions given off by the invading crystallizing magmas. However, in this region of most intense development of pegmatites, the amount of ore deposition was slight and no large ore bodies have been discovered.

Farther away from the granitic intrusion magmatic solutions given off by these igneous masses penetrated the schists and encountered conditions more favorable to the precipitation of the metallic sulphides carried in solution and deposited them. As a result the argillites and slates a few miles west of the contact, as on Cleveland Peninsula and Revillagigedo Island, are very heavily impregnated with sulphides, and in certain places the precious metals have been in quantities sufficient to form valuable deposits.

The sedimentary rocks flanking the Coast Range batholiths in this region are folded closely near the contact and more openly at a distance so that, though their general trend is parallel to the range, their dip is extremely variable, ranging from northeasterly to southwesterly at all angles. Within the granite area itself are occasional belts of included sedimentary rocks in a highly metamorphosed condition. They vary from argillites to mica, hornblende, and calcareous schists of various types, even marble, and occur in long bands, intensely folded. They still preserve in general their northwest trend, parallel to the course of the range, and their steep northeasterly dip, and they are walled in by great mountain masses of intrusive granite. Most of the included belts of schist in the Coast Range are not wide, and more appear near the mountain tops than at sea level. They can be traced up the exposed cliffs and bare mountain sides for 4,000 to 6,000 feet. They are in many places intensely mineralized with sulphides, especially pyrite, and near the mountain crests show abundant evidence of contact metamorphism and the formation of garnetiferous rocks.

A comparison of the metamorphic effects of the intrusive granite along its western and eastern flanks in the latitude of the Ketchikan district shows decided differences. On the coastal side the metamorphism near the contact is usually of the deep-seated type; gneisses and schists predominate and are cut by innumerable pegmatite dikes ramifying from the granite. Mineralization by sulphides is not pronounced near the contact. Farther west, at some distance from the contact, evidences of contact metamorphism increase and the degree of mineralization also increases, valuable ore bodies having been discovered within this zone in the Ketchikan district. Along the eastern border of the granite, on the other hand, the metamorphism is of the contact type, and argillites and slates predominate and are in many places indurated and heavily impregnated with sulphides. Well-defined ore bodies have been found near the granite contact. The geologic interpretation of these data indicates clearly that the rocks east of the massifs were less deeply buried at the time of intrusion than those on the coastal side. In other words, the inland rocks were then above the zone of deep-seated metamorphism or rock flowage and were therefore profoundly affected by the invading intrusives and accompanying pneumatolytic solutions. Furthermore, the mineral-bearing solutions emanating from the granite encountered new conditions of temperature and pressure on entering the adjacent sedimentary rocks and deposited, as supersaturated solutions in their new environment, a portion of their dissolved contents, especially the metallic sulphides and silicates.

In this large belt the phenomena of contact metamorphism are not so pronounced and concentrated as in the contact aureole of a small intrusive boss, such as at Copper Mountain. They are equally varied, though more extensive and on a larger scale. It has frequently been observed that in a small contact aureole different contact minerals occur at different distances from the intrusive mass, and that under similar conditions an evident relation exists between a given contact mineral and its distance from the invading rocks; and in a general way this law apparently holds true for this eastern contact zone of mineralized sedimentary rocks.

As further evidence of the important part played by the intrusives of the Coast Range, it may be noted that the ore deposits are apparently all later than these intrusives; that occasionally the pegmatite dikes in this area pass gradually into quartz veins, and that the evidences of contact metamorphism and the development of contact minerals such as staurolite, garnet, and andalusite are not rare in the heavily mineralized rock belts. Nearer the Coast Range the rocks now exposed were at the time of intrusion deeply buried and therefore extremely hot and under considerable pressure. The solutions, escaping from the granite and entering this complex, encountered conditions not greatly unlike those within the crystallizing granite itself, and sulphide deposition was slight. On reaching the zone of less pressure and colder rock formations, however, the ascending solutions met conditions favorable to the precipitation of sulphides and minerals closely allied to those of ordinary contact metamorphism, where heat and magmatic solutions are the prime agents of metamorphism.

OTHER INTRUSIVES.

Dikes of diabase, andesite, porphyry, and felsite are common throughout the region and cut all the older rock strata. Some of these have been indicated on the geologic map. The importance of these rocks, however, is relatively small when compared with the intrusives of the Coast Range and their accompanying dike rocks. For the most part these dikes may be considered as intrusive forms of the greenstones, andesites, and basaltic lavas. Diabase, the most widely distributed dike rock in the region, cuts the ore bodies in many places. It usually has a fine-grained ophitic texture, is dark green, and consists essentially of altered plagioclase feldspar, together with basaltic hornblende largely altered to uralite. Both magnetite and pyrite are generally present in disseminated grains. The porphyries, which may be regarded as the dike rocks of the andesitic lavas, are characterized by their porphyritic texture, by their light-green color, and by large phenocrysts of plagioclase feldspar contained in a finely crystalline groundmass. These dikes are numerous along the shore exposures, where they cut the Paleozoic strata and the granitic intrusives. Narrow dikes of basalt were observed on Kasaan Peninsula and at other localities. They are usually black, finely crystalline, and porphyritic, and vary widely in composition. The basalts are the most recent intrusive rocks.

EXTRUSIVES.

The greenstone extrusives mentioned in the foregoing pages are represented essentially by tuffaceous strata and lava flows, which have been generally metamorphosed and rendered schistose, their original mineral constituents having been replaced to large extent by secondary products. Because of this alteration the former character of the rock has in most places been obliterated, but elsewhere their texture and mineral content mark them as igneous rocks. The interstratification and the intermingling of the igneous material with the black slates indicate that most of the igneous material, composed of tuffs and some agglomerates, resulted from volcanic outbursts. Lava flows also occur, but are less frequent. They are somewhat metamorphosed, have a greenish cast, and range in composition from altered andesites and andesitic tuffs to basalts and altered gabbros.

In their most altered form the greenstone schists are fine grained and are composed largely of chlorite, calcite, and secondary hornblende, which give the rocks a dark-green color. These schists, where permeated by mineral-bearing waters, contain considerable amounts of pyrite, and in several places have been bleached to a light yellow, as on Gravina Island and Cleveland Peninsula.

As is shown on the general geologic map, the greenstones are distributed along the mainland belt including Gravina Island, Cleveland Peninsula, and Duncan Canal and are also well developed along the shores of Hetta Inlet and on Shukwan Island. The greenstones are irregularly involved with the slates, limestones, quartzites, and schists, having been folded and compressed with them, and are considered to be essentially of the same age.

The extrusive rocks provisionally referred to the Jurassic or the Cretaceous are made up of lavas and tuffs like those of the upper Carboniferous. These extrusives include altered andesites, hornblendic porphyries, quartzose porphyries, and basalt tuffs. With these extrusives are included fragmental or clastic rocks composed of volcanic tuffs, sandstones, and conglomerates. As a whole the lavas are less prominent than the clastic rocks. They are intercalated with the sedimentary slates and sandstones or graywackes. The original character and manner of deposition of extrusives must have been very similar to that of the older greenstones. They are, however, readily distinguished from the greenstones by differences in composition and texture and by their dominant reddish color, and also by a difference in the amount of apparent metamorphism of the extrusives. They have not been changed to chlorite or talcose schists and do not show the degree of alteration that is characteristic of the older greenstones. As indicated on the accompanying map, the andesites occupy irregular areas on the south end and along the west coast of Prince of Wales Island but are not known to occur in other portions of the Ketchikan district.

Basaltic lavas of postglacial age occupy small areas at many points along the mainland and on Revillagigedo Island. They lie in nearly horizontal beds on the upturned schists and granitic rocks. The massive lava dominates, but narrow beds of tuffaceous material or ash were also observed. These flows correspond to the lavas on Kruzof Island in the Sitka district to the northwest.

STRUCTURE.

A consideration of the entire coastal province of southeastern Alaska brings out several important features which throw light on the dynamic history of the region. In the Ketchikan district alone these features are not very clearly marked. Prior to the development of the main northwest-trending structural lines, which at present dominate this coastal province and are most pronounced adjacent to the wide areas of intrusive rocks, the prevalent structure was made up of northeastward-trending folds. These folds still form a minor system, prominent on the west coast of Prince of Wales Island. The later and more intense folding of the beds, on a broader scale, which forms the major system and trends northwestward, has in general obliterated this minor system. Nearer the intrusive belts the larger system gradually prevails, and the minor folds as a whole are combined in the broader anticlines and synclines of the major northwest-trending folds. Complex minor folding and fracturing is thus produced in the beds. The fact that beds of upper Carboniferous age have this northeasterly folding indicates that this was the dominant bedrock structure at the close of the Paleozoic era. Whether the younger system of folding was produced just before the intrusion of the granite of the Coast Range or at the time of its invasion has not been definitely established, though, as suggested by Spencer,[1] it was probably before the invasion of these igneous rocks, as the planes of contact, with few exceptions, follow the planes of bedding; to present this structure the strata must have been highly tilted and must have occupied a position similar to that which they now have. Along the mainland, across a width of from 5 to 10 miles, the uniformity of the strike and dip of the stratified rocks adjacent to the Coast Range batholiths indicates a monoclinal structure. Such interpretation, however, would necessitate a still greater thickness of the rock beds at the time of their deposition, as in their present condition they are greatly compressed and metamorphosed. From the evidence of broad folding of the beds it is reasonable to assume that this rock belt has the structure of a closely folded and compressed synclinorium, in which the tops of the anticlines have been removed, leaving little or no definite proof of their existence.

After this great period of mountain building, which is believed to have occurred about the close of Paleozoic or in early Mesozoic time, further important orogenic movements of the earth's crust took place and are clearly shown in the Mesozoic beds on Prince of Wales Island. In certain localities these beds overlie the granite intrusives and have assumed a steeply tilted position, with a northwesterly strike, and are considerably metamorphosed, but at other places they are only slightly folded and show no persistent direction of strike or dip and but little metamorphism. The forces producing this later structure affected the older Paleozoic strata largely by faulting, fissuring, and tilting, and not by intense folding. The structural characteristics in the more recent rock formations indicate tilting and faulting, and there is little or no evidence of folding or metamorphic action. The effects appear to be confined largely to the basins or local areas occupied by these rocks, and in the older beds faults and fissures were probably produced along which the basaltic lavas subsequently found egress.

In addition to the preceding description of the different periods of dynamic revolution, the structurally significant faulting which accompanied these orogenic movements deserves special consideration. Evidence of these faults is shown by the local discontinuity of the strata. These faults, which are possibly numerous, are parallel to the bedding, and are therefore difficult to decipher, because of the extreme metamorphism of most of the rocks.

OUTLINE OF GEOLOGIC HISTORY.

The sedimentary record in this province begins with the deposition of a series of fragmental rocks, now represented by banded quartzite, sandstone, a few beds of conglomerate, and some tuffaceous material. These clastic rocks grade upward into calcareous beds and into limestone containing a Silurian fauna. Though the age of the earliest sediments has not been determined they are believed to be mostly Silurian, as they are succeeded with apparent conformity by limestones of that age. However, since their thickness is estimated at 10,000 feet or more, it is possible that their deposition began in an earlier period. At all events the record shows that sedimentation was probably continuous during early Silurian time, when clastic rocks were deposited to a great thickness, and that there was then a gradual deepening of the sea, and several thousand feet of limestone strata were laid down. The deposition of this Silurian limestone was possibly followed by a period of earth movement, during which the rocks were indurated and more or less folded, but of this fact there is no definite proof.

The oldest representative of the Devonian system is a succession of conglomerate and sandstone beds, composed largely of igneous material, which in most places appear to be less altered than the Silurian limestones and underlying clastic rocks. The pebbles of the conglomerate are embedded in a tuffaceous matrix and were derived chiefly from the older banded quartzite and limestone strata. This series, which is estimated to be 1,200 feet thick, grades upward with apparent conformity into the Lower Devonian limestones. These calcareous beds are nearly 2,000 feet thick and their period of deposition probably extended well up into Middle Devonian time. In other parts of the region the Middle Devonian is represented by argillaceous schists and slaty limestones, but the relations between these and the early Devonian limestones are not known. After deposition of the slaty limestones and argillites and apparently conformable with them a limestone of considerable thickness was laid down in Upper Devonian

[1] Spencer, A. C., The Juneau gold belt, Alaska: U. S. Geol. Survey Bull. 287, p. 14, 1906.

time. This later limestone, though highly crystalline and in places folded, does not generally show the intensity of dynamic action which characterizes the older limestones.

The Carboniferous period seems to have been begun by the deposition of gray limestone beds 1,500 feet or more in thickness, and, though the relations between these beds and the underlying Devonian strata have not been clearly determined, it is probable that a deep sea covered this region from late Devonian to early Carboniferous time. Along the mainland the corresponding limestone beds are infolded with argillites and crystalline schists and are highly metamorphosed. These argillites are, in part at least, Mesozoic. A long period of volcanic activity followed. The beds of lava and ash ejected from the volcanic vents were contemporaneous with the slate beds, and because of their intimate association with the sediments the volcanics are regarded as submarine extrusives. They are now represented by the altered massive greenstones and greenstone schists, which are widely exposed throughout the region and, together with the interstratified slate beds, have a thickness estimated at about 4,000 feet.

The sequence of geologic events during the Mesozoic era is not clearly defined because of the lack of paleontologic and structural evidence and because of the great orogenic changes which took place during this era. During early Mesozoic time the bedded rocks suffered intense metamorphism and recrystallization, resulting in the conversion of the sedimentary strata to schists and slates and in the alterations of the volcanic rocks to amphibole schists and chloritic greenstones. At the same time the beds were highly tilted and intricately folded, the direction of the axes of folding being generally southeast. These changes are exemplified more clearly in the beds flanking the Coast Range than in the sedimentary rocks composing the outer islands. Early Mesozoic slates have been recognized in the Berners Bay district, and, as suggested by Brooks,[1] probably Triassic beds are infolded with these older metamorphosed sediments in the Ketchikan district. The large development of the Triassic deposits to the south in British Columbia points to the same conclusion.

The most important event in this district during Mesozoic time was the intrusion of the great batholiths of the Coast Range. A study of the section across the axial mass of the Coast Range itself shows that the mass is not a simple batholith but is made up of successive intrusions along the same general line of weakness in the earth's crust. On the outlying islands granitic masses, which are much altered and contain many shearing planes, are invaded by granitic intrusives only slightly altered, which in turn are intruded by pegmatitic dikes and masses. Between these successive intrusions considerable time probably elapsed. The main folding and tilting of the bedded rocks referred to above probably preceded the actual invasion of the granodioritic rocks, as suggested by Spencer,[2] a suggestion based on the fact that their lines of intrusion are in a broad way parallel to the bedding planes and schistosity of these older rocks, also on the fact that a few inclusions of schist fragments occur within the intrusive massif. In order to control thus effectively the lines of intrusion of the granodiorites, the invaded sedimentaries must have been highly tilted previous to the time of igneous intrusions.

Observations made in southeastern Alaska and elsewhere show that the geologic processes which combined to produce these vast intrusions and structural phenomena acted very slowly and over long periods of time. Though the Coast Range intrusion is generally considered as having occurred at one period, a conclusion that is undoubtedly true for limited areas, it is probable that in southeastern Alaska, at least, considerable time intervened between the first granite invasion and the final solidification of the last intrusive masses. It is not possible now to refer these granitic intrusions in this province to a definite geologic period, but the evidence available in adjacent provinces indicates that they continued at least until late Middle Jurassic time. These invasions of igneous material were evidently the cause of the vast amount of metamorphism and deformation of the sedimentary strata along their contacts, and it is also probable that many of the ore bodies were deposited just after these igneous invasions, the intrusive containing the material forming the ore. The transfer of igneous material to points

[1] Brooks, A. H., Ketchikan mining district: U. S. Geol. Survey Prof. Paper 1, pp. 22-28, 1902.

[2] Spencer, A. C., op. cit., p. 19.

nearer the earth's surface naturally produced strains in the earth's crust, which found relief in cracks and fissures and lines of brecciation at the contacts of the intrusives and elsewhere. The lines of weakness thus formed furnished channels that afforded free circulation for mineralizing solutions, which are believed to have been derived for the most part from the igneous masses themselves and to have been given off while the masses were in process of solidification.

A period of erosion appears to have followed the intrusion of the Mesozoic granite, and later another epoch of volcanism began. The volcanic rocks of this later epoch are represented by tuffaceous deposits and lavas that occupy considerable areas in the southern and western parts of Prince of Wales Island where they lie on the eroded surface of the granite and are overlain by or interstratified with deposits of plastic rock. The steeply tilted attitude and metamorphosed condition of these volcanic rocks indicate that they were considerably folded but that the structural deformation was not widespread, as it did not greatly modify the early Mesozoic folding which preceded the intrusion of the granite.

The deposition and folding of these Mesozoic strata appear to have been followed by a a long period of quiescence, during which erosion was probably extensive. In upper Eocene time sedimentation took place in local basins. The beds then formed, including fine conglomerate and shales with some lignite, were subsequently tilted and faulted, but this disturbance was apparently local. No evidence of marine life has been found in them and probably they were fresh-water accumulations. They occur only near sea level and in low-lying valleys and basins practically inclosed by mountains of granite and older metamorphosed rocks. These beds represent the most recent sedimentary formations of the Ketchikan district and after their deposition wide areas of land were flooded by basaltic lavas which poured forth through fissures in enormous volume. These lava flows are flat-lying and on Kuiu Island in the Wrangell district attain a thickness of over 1,500 feet. They were probably extruded at the close of the Eocene.

A large part of the Tertiary sediments may have been subsequently removed by erosion, for there must have been a long period of quiescence after their deposition and deformation. The next important event in the region was the development of the ice sheet which covered the entire district. Its retreat left the topography in essentially its present form. After the retreat of the ice some lava sheets were locally erupted.

GENERAL DISTRIBUTION OF MINERALIZATION.

Within the mainland belt and in the eastern part of Revillagigedo Island, in the Ketchikan district, mineralization is scattered both in the granitic intrusives and the adjacent schists, but mineralized zones corresponding to those in the Juneau gold belt to the north are less strongly marked. Quartz veins and metallic impregnations are found only locally, and prospecting has revealed comparatively few valuable ore deposits in the areas occupied by these rocks. Explorations have been confined, however, mainly to the shores of the deep, narrow fiords, from which the mountains rise abruptly to high altitudes. Steep, forest-covered slopes make prospecting difficult and have restricted the knowledge of the greater portion of the schist belt to the vicinity of salt water. The ore bodies thus far disclosed have been developed near Smeaton Bay in Behm Canal; at Sealevel, on the northeast side of Thorne Arm; and near the head of Carroll Inlet. For the most part they consist of simple veins in fissures and lode deposits of complex composition. They contain only moderate values in gold.

In the slate-greenstone belt, which borders Tongass Narrows and includes the western part of Cleveland Peninsula, ore bodies of considerable importance have been formed. They are largely lode deposits or mineralized bands, within which the greenstone schist country rock has been sheared and fissured and then permeated by the mineral-bearing solutions. In these mineralized bands or lode deposits the country rock has a bleached appearance and is impregnated with small cubes of pyrite and other sulphides. Local narrow seams of massive sulphide ore are found and native gold is seen here and there in the vein quartz or appears as thin films or flakes along the jointing cracks and slipping planes. Besides gold and small amounts of silver, copper also occurs in slight amounts in some of the deposits of these rocks.

Though quartz veins are prominent throughout the slate and greenstone belt, some of which show particles of native gold, most of them are too small or their gold content is too low to pay for mining.

On Prince of Wales Island the regularity of the rock structure is locally interrupted by broad, irregular areas of intrusive granitic rocks, and for this reason the ore bodies are not traceable along definite zones. Mineralization is in general closely related to the intrusive rock masses, and many of the deposits are at the contacts of the intrusives or in their vicinity. They occur as large lenticular bodies and as veins of nearly massive sulphide ore composed of pyrite, chalcopyrite, magnetite, and pyrrhotite in a matrix of garnet, quartz, calcite, and other gangue minerals. Such deposits are found on Copper Mountain and on Kasaan Peninsula. Bodies of copper ore inclosed in a greenstone schist country rock, both in lenticular masses and in veins, occur at Niblack Anchorage, at the head of North Arm, and in Hetta Inlet. Bornite and chalcopyrite occur in small patches that are in places disseminated through the granitic intrusives and are being explored on the Goodro claims to the northeast of Karta Bay.

On Prince of Wales Island gold ores are confined principally to the limestones and phyllites and are being mined in the vicinity of Hollis, on Cholmondeley Sound, and at Dolomi. At these points the gold occurs in veins of quartz and in lodes following lines of brecciation in the limestone. It is commonly present in the native form and is in many places accompanied by considerable amounts of silver and copper. The principal ore minerals are pyrite, galena, sphalerite, and tetrahedrite.

Auriferous veins in the granitic intrusives have been located and partly developed on Granite Mountain to the west of Karta Bay, at several points in the vicinity of Shakan, and at Ratz Harbor in Clarence Straits. These veins show that the granitic areas are not everywhere barren of ore, as often assumed.

Ores of silver, lead, and zinc have been observed at several localities on Prince of Wales Island, though the only deposit that has been developed is on the Moonshine claim, in Cholmondeley Sound. At this place the ore occurs in a well-defined vein traversing the limestone and greenstone schist country rock.

COPPER MOUNTAIN AREA.

TOPOGRAPHY.

The Copper Mountain area as here defined embraces about 86 square miles of rugged country on the west side of Prince of Wales Island. (See Pl. II.) It takes its name from Copper Mountain (altitude, 3,946 feet), which marks the center of the area. This mountain and other peaks, such as Mount Jumbo (3,464 feet), Hetta Mountain (2, 961 feet), Billie Mountain (3,250 feet), Green Monster Mountain (2,900 feet), and their connecting ridges and spurs form a rugged highland which is bounded on the west and north by Hetta Inlet (see Pls. III, *A*, and IV, *B*), a deep embayment of Prince of Wales Island. On the east the upland merges into the unmapped mountains of Prince of Wales Island. Hetta Inlet is bounded on the north and west by highlands, only the lower slopes of which have been mapped. Among these is Beaver Mountain, about 3,000 feet in height, occupying the northeast side of the area here considered. Hetta Inlet is for the most part bordered by steep slopes that rise directly from the water or from a narrow rocky beach. Only at the mouths of the larger streams, like Portage, Reynolds, and Hetta creeks, are there any flats, and these are of small extent.

The drainageways are arranged radially, their heads centering around the higher peaks. The valleys have steep slopes and their upper parts have high gradients. Practically none of the valleys exceed 2 miles in length. Lakes are plentiful and occur at many altitudes, occupying basins from 100 to nearly 2,000 feet above sea level. The larger of these are Hetta Lake, in the southern part of the area, and Lake Mellen, Summit Lake, and Lake Josephine, in the central part. These lakes are of glacial origin. The heads of the valleys lie in amphitheater-like basins or glacial cirques, especially those on the northwest slopes of the mountains. Typical glacial cirques occur in Jumbo Basin, at the head of Jumbo Valley (see Pl. III, *A*), and in

TOPOGRAPHIC MAP OF COPPER MOUNTAIN AND VICINITY, ALASKA

Alfred H. Brooks, Geologist in charge of division.
Topography by R.H. Sargent.
Control by Coast and Geodetic Survey and R.H. Sargent.
Surveyed in 1908.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 Miles

1 ½ 0 1 2 Kilometers

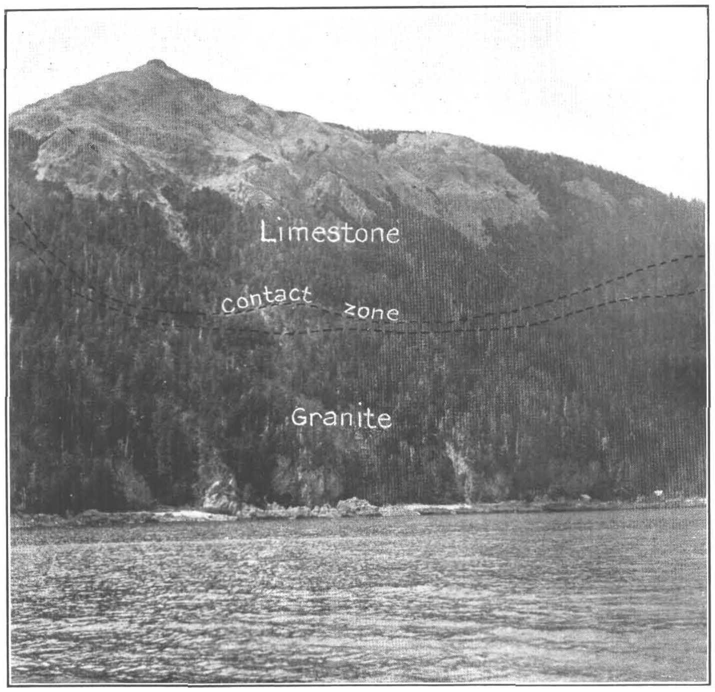
Contour interval 100 feet.

Datum is mean sea level.

Dotted lines represent approximate topography.

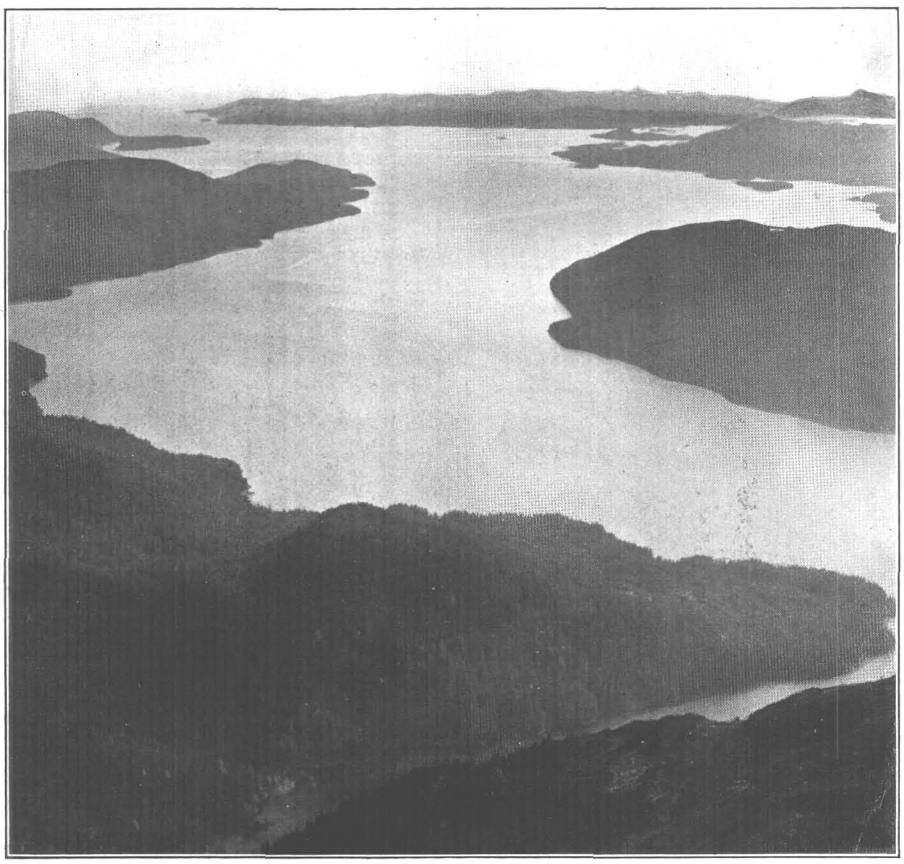
1914

TRUE NORTH
MAGNETIC NORTH
30°
APPROXIMATE MEAN DECLINATION 1908.



A. GREEN MONSTER MOUNTAIN FROM SOUTH SIDE OF SUMMIT LAKE.

Photograph by Winter & Pond.



B. HETTA INLET LOOKING SOUTHWARD FROM COPPER MOUNTAIN.

Copper Harbor in the foreground. Photograph by Winter & Pond.

Hetta Basin, at the head of Wright Creek. The glacial character of the topographic sculpture in the area is further manifested by the occurrence of bowlders and gravel wash in the lower parts of the valleys and by glacial markings on some of the granite knobs.

The mountain slopes are covered with a luxuriant growth of timber and underbrush up to an elevation of 2,000 feet, the timber being useful to the mine operator, though the underbrush renders prospecting difficult. (See Pl. III, *A*.) The mountain lakes form large reservoirs which may furnish a supply of water for use in both mining and smelting.

A broad valley extending eastward from the head of Hetta Inlet and connecting by a low pass with a stream flowing into the head of Cholmondeley Sound furnishes a route of communication between the western and the eastern parts of the island. A wagon road about 4 miles long has been built across this pass.

GEOLOGY.

GENERAL FEATURES.

The general geology and mineral resources of this area have been briefly described in previous reports,[1] but a more detailed statement concerning the geology and ore deposits will be given here. The most striking geologic feature of the area is the irregular granitic intrusive mass that occupies its central part. (See Pl. V.) From this mass spurs or dikes 300 to 600 feet wide diverge into the surrounding series of metamorphic schists and the interstratified beds of limestone. The schists are much wrinkled and sheared and include both calcareous and siliceous varieties, and the limestones are generally marmarized. The rocks nearer the intrusive contact are further altered to a hornfels or amphibolite, which is usually banded with parallel beds containing much garnet and diopside. The principal limestone belt extends from Copper Harbor northwestward into Jumbo Basin, and another belt occurs on Green Monster Mountain (see Pl. IV, *A*) and Hetta Mountain. Narrow bands of schist are interstratified with these limestones, and in turn narrow beds of limestone are interstratified with the schists. Southwest of the main limestone belt on the west slope of Copper Mountain the limestone is overlain by a considerable thickness of altered siliceous schists, which lie conformably on the limestone and grade upward into a succession of amphibole and chlorite schists that are interstratified with quartzites and show no limestone. These chlorite and amphibole schists are interstratified with quartzites, slates, and here and there beds of a massive greenstone that probably represents an ancient lava. They border the east and west shores of Hetta Inlet (see Pl. IV, *B*) and are the most recent bedded rocks in the area.

SEDIMENTARY ROCKS.

The sedimentary rocks within the Copper Mountain area are, as already noted, made up of highly metamorphosed schists and limestones, probably chiefly of Paleozoic age (Carboniferous?). They occupy a steeply tilted position surrounding the granitic intrusive mass. These stratified rocks fall into two divisions—a lower, made up of metamorphic schists and limestones, and an upper, made up of volcanics with some clastics. The distribution of these rocks is indicated on the geologic map. (See Pl. V.)

SCHISTS.

The oldest rocks of the Copper Mountain area are made up of metamorphosed schists composed largely of sedimentary material, though in places they include tuffaceous material and extensive limestone beds. These rocks surround the granitic intrusive masses and are important because of their relations to and influence on the ore deposits.

The schists are for the most part fine grained and crystalline, with amphibole, mica, and quartz as their principal mineral constituents, though in some feldspar, calcite, or chlorite

[1] Brooks, A. H., Preliminary report on the Ketchikan mining district, Alaska, with an introductory sketch of southeastern Alaska: U. S. Geol. Survey Prof. Paper 1, 1902. Brooks, A. H., and others, Report on progress of investigations of mineral resources of Alaska in 1905: U. S. Geol. Survey Bull. 284, 1906; Report on progress of investigations of mineral resources of Alaska in 1906: U. S. Geol. Survey Bull. 314, 1907; Mineral resources of Alaska (report on progress of investigations in 1907): U. S. Geol. Survey Bull. 345, 1908; Mineral resources of Alaska (report on progress of investigations in 1908): U. S. Geol. Survey Bull. 379, 1909.

may predominate, and at points near the granitic intrusives they are composed essentially of garnet, epidote, or diopside, with quartz and some magnetite or pyrite. Certain strata consist of carbonaceous, argillaceous schists with local development of graphite; phyllites also occur. Some of the specimens collected resemble a biotite gneiss; they are massive, though much wrinkled, and from the hand specimens their origin is difficult to determine. Calcareous bands occur in these more gneissic schists, and on their weathered surface are projecting ribs of biotite with some quartz.

These rocks are presumably derived for the most part by alteration from argillaceous and calcareous sediments that have been largely crystallized by intense metamorphic action, though some of the schistose strata may represent metamorphosed igneous rocks of volcanic origin.

LIMESTONES.

Thickness and character.—Beds of altered limestone are interstratified with the schists and evidently belong to the same period of deposition. These beds range in thickness from less than 100 feet to more than 1,000 feet. The limestone varies from a white, coarse, crystalline marble to a dark-blue to nearly black, in places finely crystalline to granular though locally thin-bedded and slaty limestone. This change in appearance is due not so much to a change in composition as to a change in alteration or crystallization, this being in part attributable to contact metamorphism caused by the granitic intrusives and in part to regional metamorphism.

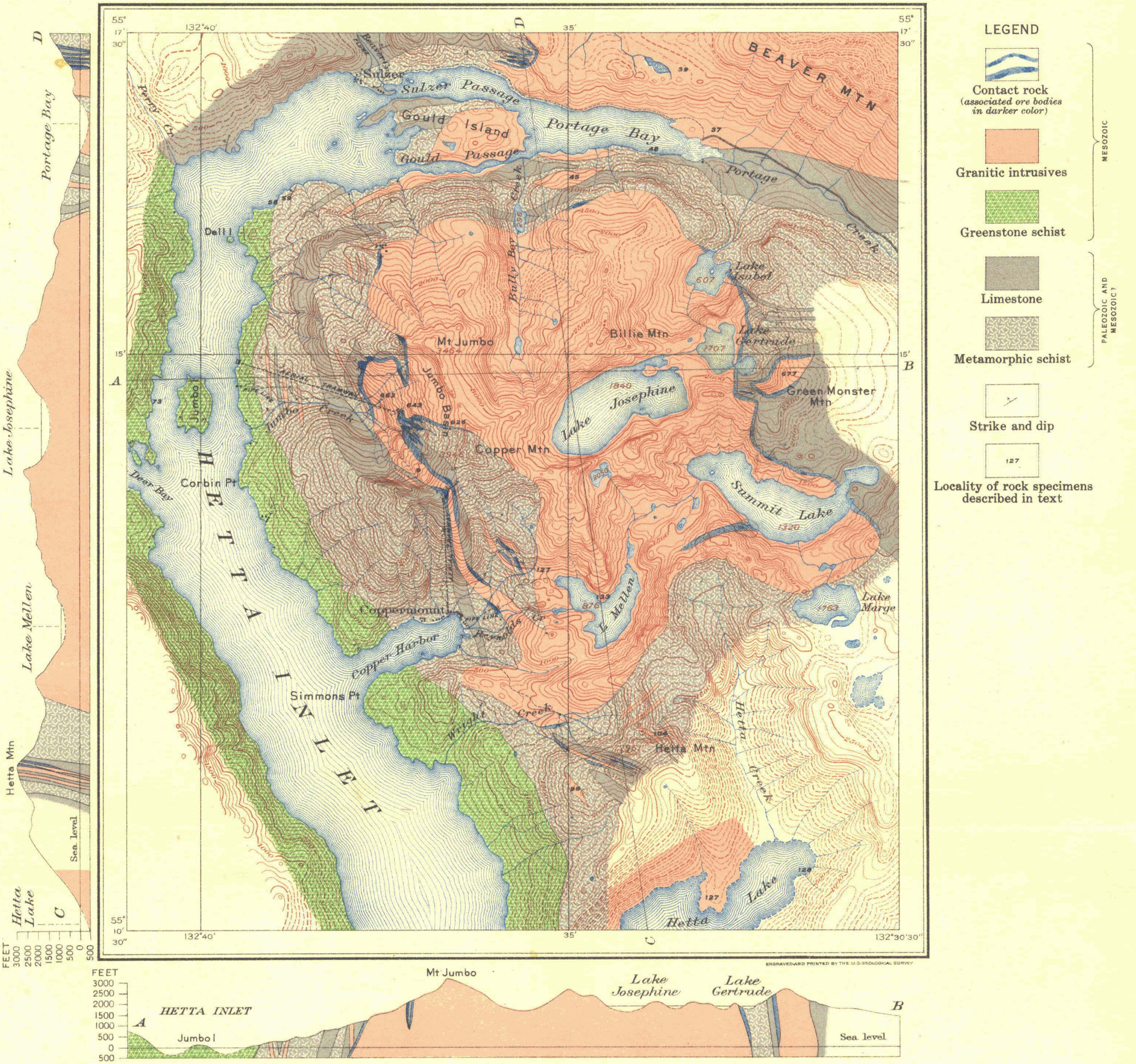
In the hand specimen the crystallized limestone is white with occasional gray patches, granular in texture (average granularity about 1 millimeter), and consists almost entirely of calcite. Under the microscope it appears to be composed almost exclusively of lime carbonate, with rarely a speck of magnetite. The carbonate is evenly granular and intricately twinned.

This rock is the country rock into which the granodiorite of the Jumbo property is intruded and along the narrow margin of which the copper-bearing contact deposits have been formed. An analysis of the limestone from this mine, by George Steiger, is as follows:

Analysis of limestone from Jumbo mine.

SiO_2	0.61
Al_2O_3	.30
Fe_2O_3	.48
MgO	8.00
CaO	46.45
H_2O	.22
CO_2	44.07
S	.06
MnO	.03
	100.22

Occurrence.—These schists and limestones form a nearly continuous belt around the granitic mass which occupies the central portion of the area. In places the limestone members are at the contact, though in general the schists border the intrusive mass. The total thickness of these rocks is difficult to determine because of the folding and compression to which the rocks have been subjected, but it is probably 5,000 feet or more. In Jumbo Basin a wide mass of schist and limestone, which also extends southward over Copper Mountain, is completely surrounded by the intrusive rock. Tongues and small masses of the granitic rock are surrounded by the schists. Near the intrusive contact in the upper part of Jumbo Basin the limestones are marmarized and the schists are silicified or garnetized, whereas lower in the valley, at points away from the contact, the limestone is a blue, finely crystalline rock and the schists are more argillaceous and slaty. On the shore of Hetta Inlet opposite Gould Island and on the mountain slopes the schists and limestones are highly altered and are crosscut by granitic and pegmatitic dikes. They have a general east to northeast trend, approximately parallel to that of the intrusive contact. Some of the strata are mineralized with pyrite and contain also some chalcopyrite. In places they are much wrinkled and resemble gneissoid rocks. On Green



GEOLOGIC MAP AND SECTIONS OF COPPER MOUNTAIN AND VICINITY, ALASKA

By C. W. Wright

Surveyed in 1908 under the direction of Alfred H. Brooks

Scale $\frac{1}{62500}$

1 ½ 0 1 2 Miles

1 ½ 0 1 2 Kilometers

Contour interval 100 feet.

Datum is mean sea level.

1914

House Doc. ; 63d Cong., 2d Sess.

Monster Mountain and along the ridge just north of it the schists and limestones form narrow interstratified belts, 50 to 500 feet wide, striking in a west to northwest direction, nearly at right angles to the intrusive contact. The limestones are marmarized though somewhat siliceous, and the dominating schist is a brown mica-quartz schist, much wrinkled and containing quartz seams. On the south side of Summit Lake a belt of altered schist about 300 feet wide is included in the granite. This belt strikes southwest and has a nearly vertical dip. It is almost entirely altered to contact rock, its original schistose structure having nearly disappeared, but it shows a distinct banding of the amphiboles and mica, and the adjacent granite includes fragments which may have been derived from the schist.

The basic amphibole schists and the siliceous mica schists both occur on Hetta Mountain and along the southern contact of the intrusive mass, the former on the east slope and the latter on the west slope. The schistosity is nearly at right angles to the intrusive contact and the schists appear to be more compact and show more wrinkling than at the points where they lie parallel with the intrusive contact.

The limestone that forms a belt near Hetta Mountain is a white to bluish crystalline rock and is cut by several granitic dikes.

Age.—These limestones and schists resemble both stratigraphically and petrographically the metamorphic rocks adjacent to the Coast Range batholiths along the seaward side of the mainland. (See p. 16.) The rocks bordering the mainland have been described as the Ketchikan series by Brooks and as the schist band by Spencer. Fossils found in the mainland belt of limestones indicate that they include Carboniferous and probably some Mesozoic strata.

Structure.—Cleavage is usually well developed in the schists where they contain considerable amphibole or mica. The more siliceous beds and those near the contact of granitic intrusives that contain infiltrations of garnet, diopside, or epidote, and also the limestones, do not show this pronounced cleavage but in places show cleavage at right angles to the bedding. It is noteworthy that the lines of schistosity correspond to those of the bedding, a fact that is made evident by the occurrence of the interstratified limestone beds. The stratification of these bedded rocks is indicated at many points on the geologic map by symbols indicating strike and dip. It is clear that the present structure is in large measure due to the influence of the intruded granitic mass. The beds farther south strike northwestward, at right angles to the granite contact, though those on the west and east sides of the granite mass are parallel to the contact both in strike and dip, as are some of those on the north side of the main intrusive mass, where the bedded rocks have an east-west strike and almost vertical dip, and occupy a position between two main granitic masses. (See Pl. VI, *A*.)

Metamorphism.—The alteration of these rocks to crystalline schists is ordinarily attributed to regional metamorphism, which is supposed to have been produced by mountain-building forces operating when the rocks were deeply buried. It is probable that the general metamorphism was effected at an earlier date than that of the granitic intrusion, though a considerable amount of metamorphism may be attributable to the intrusion of the granitic masses. The alterations due to contact metamorphism are considered elsewhere in this report.

GREENSTONE SCHISTS.

Character.—The succeeding strata differ somewhat both in composition and origin, but are principally greenstone schists composed largely of igneous material interbedded with some siliceous sedimentary material. They consist of amphibole and chlorite schists and quartzites. and contain, in places, argillaceous interstratified beds of phyllite and graphitic schists.

The greenstone schists probably represent altered andesite or diabase tuffs and lavas. Their component minerals, most of which are secondary, are in the main amphibole, altered plagioclase feldspar, epidote, chlorite, calcite, quartz, and magnetite. The original plagioclase feldspar is generally altered to zoisite and muscovite and the pyroxenes are changed to amphibole. The microscope shows that the less altered greenstone schists were derived from an igneous rock, probably an augite andesite. The augite, however, is represented by amphibole that occurs in minute needles. The minerals differ in amount in different strata and the rock may be called amphibole schist, actinolite schist, chlorite schist, calcareous schist, or siliceous schist, its designation depending on its mineral composition.

These greenstone schists grade without definite boundaries into a rock composed partly of igneous and partly of sedimentary material, and this in turn grades into a quartzite or a siliceous argillite, composed mainly of sedimentary material. The intercalation of the greenstone schists with the sedimentary beds suggests that they represent extrusives of igneous material thrown out over the sea bottom as volcanic tuff and in some places as a lava bed.

Included quartzite.—The sedimentary beds interstratified with the greenstone schists are indurated, fine-grained to aphanitic rocks, in places showing banded layers, and ranging in color from light gray to dark green. They usually contain pyrite and weather brown on the surface. They do not break easily along the bedding planes but fracture more readily along joint cracks, breaking at right angles to the bedding.

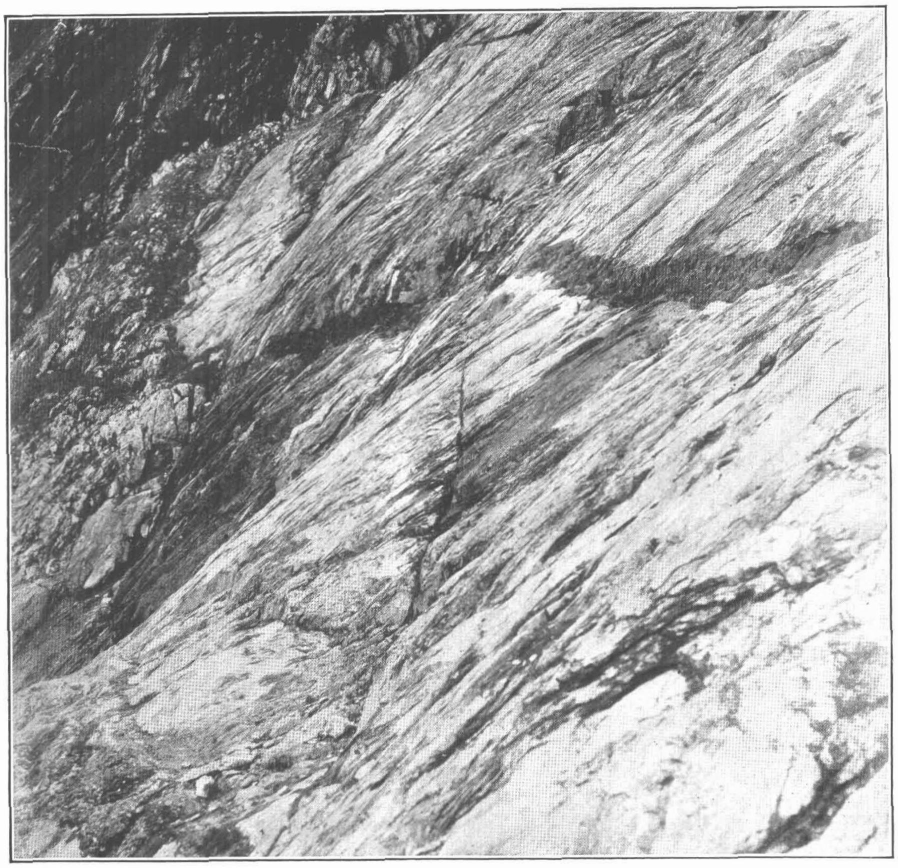
Occurrence.—The greenstone schists border both sides of the main northwest channel of Hetta Inlet, but do not extend along its eastern branch. (See Pl. I.) On the west slope of Copper Mountain they extend to an elevation of about 1,000 feet, where the interstratified greenstone schist members gradually disappear and the quartz-mica schists of the older series are found. No sharp line of demarcation can be drawn between these two formations, and the division is made where the greenstone volcanic material ceases to occur in the stratified rocks.

Near the shore line at the foot of Copper Mountain certain strata of the greenstone schists have a bleached appearance and are of a pale-green color. These rocks contain both pyrite and chalcopyrite as well as quartz stringers and kidneys of quartz and calcite. In places these mineralized strata contain large amounts of copper.

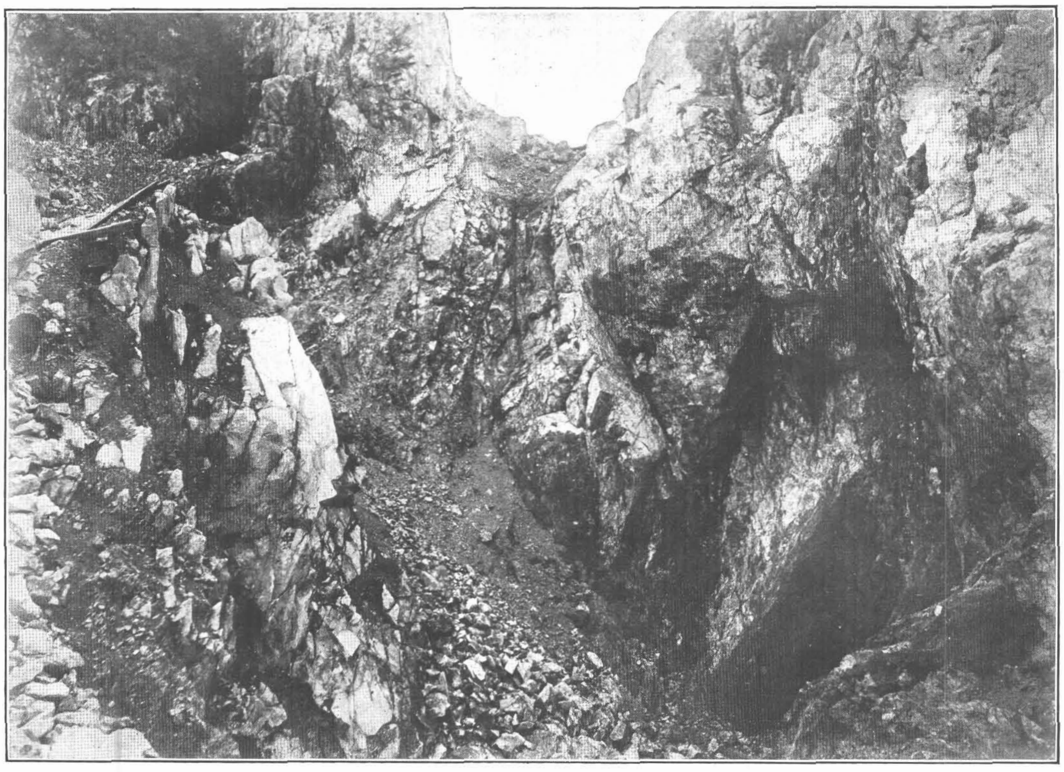
Age.—The greenstones and associated sediments of the Copper Mountain area resemble lithologically the rocks of the mainland belt already described (p. 16). Here, however, the quartzites dominate over the slates. As in the mainland belt, the greenstones are closely associated with limestones that are believed to be of Carboniferous age. In the Copper Mountain region, however, they are clearly younger than the limestones. The slate, graywacke, and greenstone belt of the mainland is in part, at least, Mesozoic, and in the absence of evidence to the contrary it is therefore fair to assume that the greenstones of Copper Mountain are also of Mesozoic age.

Structure.—The structure of the greenstones is much simpler than that of the older schists and limestones. These rocks strike north to northwest and dip NE. 30° to 75°. On the east shore of Hetta Inlet the dip is usually 15° to 30° less than along the west shore. They overlie the metamorphic schists with apparent conformity. They show prominent jointing planes, especially along the west shore of Hetta Inlet, and these strike in general from N. 75° W. to N. 75° E., nearly at right angles to the schistosity, though their dip is almost vertical. Dikes of diabase and basalt, cutting the greenstones and invariably following the direction of the jointing planes, are common.

Metamorphism.—The metamorphism of the greenstones is similar to but less intense than that of the schists and limestones already described. It was doubtless produced by the same forces and during the same periods. The associated sedimentary rocks were originally sandstones, shales, and tuffs, more or less intermixed. The sandstones have been changed to quartzite, the shales to carbonaceous and sericitic schists, and the tuffs to chlorite schists, and just as these originally sedimentary rock beds graded one into the other so do their metamorphic representatives. The metamorphic processes that effected these changes caused a breaking up of the original minerals into secondary minerals, such as the alteration of feldspar to kaolin and sericite and of hornblende and pyroxene to chlorite, serpentine, calcite, and quartz. The combination of these minerals by metamorphism forms other minerals, such as andalusite and staurolite, but such occurrences were rarely noted in the Copper Mountain area.



A. SILICEOUS SCHISTS ON MOUNTAIN SIDE BELOW NEW YORK CLAIM.
Showing basic dike crosscutting the schists. Elevation, 2,500 feet.



B. CONTACT ORE DEPOSIT ON NEW YORK CLAIM, COPPER MOUNTAIN.
Crystalline limestone on right; altered granitic intrusive rock on left.

IGNEOUS ROCKS.

GENERAL FEATURES.

The detailed petrographic and microscopic study of the igneous and contact rocks of this region was kindly undertaken for the writer by Dr. H. E. Merwin, of the Geophysical Laboratory of the Carnegie Institution of Washington. The results of Dr. Merwin's investigations are given in detail in this report.

Coarse-grained massive igneous rocks, occurring as batholiths, occupy nearly half the surface of the Copper Mountain area. Collectively these rocks are commonly called granite, and they have all been mapped in one color under the name of "granitic intrusives." They comprise, however, rocks of several types, which differ widely in composition, and in some places a change in mineral components was noted from part to part of the same mass. These granitic intrusive rocks form the most important geologic feature in the area, principally because the main ore deposits are found at their contacts and were formed at the time of their intrusion. The relations of these intrusives to the ore deposits and the phenomena observed at the contacts are discussed at length in this report.

Other intrusive rocks of minor extent occur within the area in the form of dikes. These dike rocks include granite porphyry, diorite porphyry, pegmatite, aplite, lamprophyre, diabase, and basalt.

GRANITIC INTRUSIVES.

TYPES.

The batholith rock masses in the Copper Mountain area include granitic intrusives of several distinct types, their differences depending largely on the proportions of their component minerals. The factor of greatest influence in determining the rock type is the presence and proportion of orthoclase feldspar. The main type is a diorite, though the proportion of orthoclase may increase in different parts of the same batholithic intrusive mass, and the rock must then be classed as monzonite or, where orthoclase dominates the rock, as syenite. No well-defined lines can be drawn between such variations of the rock type; it is possible to recognize them only by microscopic study of specimens.

These rocks include few true granites, as the proportion of quartz they contain is generally small. A basic type of the granitic intrusives is represented by the gabbros that form some of the smaller batholithic masses. The distinctions between the different rock types are emphasized in the petrographic descriptions.

DIORITE.

The diorite is a coarse to medium grained rock, light to dark gray in color, made up essentially of plagioclase feldspar and hornblende, though in places containing biotite and occasionally pyroxene, as well as small amounts of orthoclase and some quartz, magnetite, titanite, and apatite. The central portions of the diorite batholiths are rather uniform in composition and texture, though near the contact they become less uniform in color and are marked by dark spots, most of which are segregations of hornblende, and in places they are traversed by veins of pegmatite. A type specimen of the diorite (specimen J 4) collected in Jumbo Basin near the mine on Jumbo No. 4 claim, though far enough back from the contact to be free from all secondary alteration, is described below.

The type specimens of diorite were collected principally from Jumbo Basin (specimens 662, 645 to 649) and Beaver Mountain (specimens 39 and 37). They include both hornblende diorite and augite diorite, which in appearance are practically the same as the granodiorite. Rocks of these two types make up the greater part of the granitic intrusives, and it is not possible to define them separately as regards their distribution, as the one evidently grades into the other.

The microscopic petrography of these rocks is described below by Dr. H. E. Merwin.

Specimen J 4: A granitoid rock of medium grain, containing about the following percentages of essential mineral constituents: Quartz, 10; plagioclase, 50; orthoclase, 30; hornblende, 5;

augite, 5; and small amounts of accessory biotite, apatite, titanite, and magnetite. The plagioclase ranges from labradorite to oligoclase, averaging about Ab_2An_1. The central, more calcic zones are altered to epidote.

An analysis of the rock by George Steiger and a calculation of the normative mineral composition is as follows:

Analysis of specimen of diorite from Jumbo Basin.

SiO_2	59.44	TiO_2	0.66
Al_2O_3	17.40	ZrO_2	None.
Fe_2O_3	3.30	CO_2	None.
FeO	2.77	P_2O_5	.28
MgO	1.81	S	.02
CaO	6.51	MnO	.17
Na_2O	4.22	BaO	.07
K_2O	3.12	SrO	.05
H_2O-	.06		
H_2O+	.56		100.44

Mineral composition of specimen of diorite from Jumbo Basin.

Quartz	8.94	Magnetite	4.87
Orthoclase	18.35	Ilmenite	1.37
Albite	35.63	Apatite	.67
Anorthite	19.46	(Water)	.62
Diopside	8.68		
Hypersthene	1.93		100.52

It is evident that the single slide examined did not closely represent the rock analyzed, particularly in respect to the proportion of normative orthoclase and plagioclase. It should be borne in mind, however, that the amount of orthoclase in a rock may be considerably greater than the amount of pure potassium feldspar, on account of the albite which may be held in solid solution. The normative composition places the rock in the group andose.

Specimen 662. Collected from main intrusive mass on trail 500 feet below head of aerial tram, Jumbo Basin.

A granitic rock of medium-grained texture and greenish-gray color. It consists of plagioclase, pyroxene, and biotite, the dark-colored constituents composing 35 to 40 per cent of the rock. In the thin section the plagioclase appears in anhedral grains zoned and twinned. It averages about Ab_2An_1 in composition, ranging from oligoclase to labradorite. The pyroxene is in subhedral grains, nearly colorless except in uralitized areas, where it is greenish. Small grains of plagioclase are included in the pyroxene, which constitutes about 30 per cent of the rock and is essentially augite, but includes some diopside. About 5 per cent of interstitial orthoclase is present. Accessory minerals are biotite, quartz, magnetite, and apatite in relatively large prisms; also titanite.

The rock is an augite diorite.

Specimen 8. Collected from branch of main intrusive mass on south side of Jumbo Basin at an elevation of 2,500 feet.

Both in the hand specimen and in the thin section this rock resembles specimen 662, collected from the main intrusive mass of Jumbo Basin, but it is slightly finer grained and contains zircon.

Specimen 643. Collected from main intrusive mass northeast of head of aerial tram in Jumbo Basin at an altitude of 600 feet.

This rock is medium grained, light gray, and consists of plagioclase and hornblende and small amounts of orthoclase, quartz, pyroxene, and titanite. The plagioclase is zoned andesine, and constitutes 60 per cent of the rock. The hornblende is pleochroic in bright greens and light yellows and some of it contains irregular kernels of diopside. Quartz is a very minor constituent. Orthoclase is abundant, comprising about 20 per cent of the rock. The accessory minerals are biotite, magnetite, apatite, titanite, and zircon.

The rock is a hornblende diorite differing from the preceding in containing much more orthoclase and hornblende instead of augite.

Specimen 39. Collected from intrusive mass of Beaver Mountain north of head of Portage Bay at an elevation of 1,000 feet.

A gray granitic rock of medium grain, showing plagioclase and much hornblende and orthoclase. The slide contains about 40 per cent of zoned oligoclase and labradorite, and 35 per cent of poikilitic hornblende inclosing plagioclase, apatite, magnetite, and kernels of diopside. It is remarkably pleochroic, ranging from bright greenish blue to light yellow-brown and deep brown. It contains 15 per cent of interstitial orthoclase. The accessory minerals, which amount to about 7 per cent, include diopside, biotite, magnetite, titanite, and apatite.

This rock is a hornblende diorite.

Specimen 37. Collected from intrusive mass of Beaver Mountain, at head of Portage Bay.

This diorite is similar in appearance to specimen 39, though it includes larger flakes of biotite and, as seen in the thin section, less hornblende, in place of which it contains from 5 to 10 per cent of diopside and augite. It carries also more orthoclase, containing at least 25 per cent.

GRANODIORITE.

The granodiorite is a medium to coarse grained hypidiomorphic light-gray rock composed essentially of oligoclase feldspar, quartz, orthoclase, and hornblende or biotite. Common accessory minerals are pyroxene, titanite, apatite, and magnetite.

Type specimens of the granodiorite were collected from the main intrusive mass along the shore of Mellen (specimen 133) and Summit lakes and from adjacent batholithic masses on the shore of Hetta Lake (specimen 127) and on Green Monster Mountain (specimen 677). At these localities the rock is practically fresh, showing little or no development of secondary minerals. In composition it is apparently uniform and shows little or no segregation of minerals.

The microscopic petrography of the specimens was studied by Dr. H. E. Merwin and is described below.

Specimen 133. Collected from main intrusive mass at point on north side of Lake Mellen. The hand specimen is medium grained, grayish, and contains well-formed prismatic crystals of hornblende and much plagioclase; also some quartz and orthoclase. Under the microscope the rock shows about 60 per cent plagioclase in subhedral crystals polysynthetically twinned and zoned. The composition of the zones varies from albite to andesine. The hornblende, the other chief constituent, is light yellow to deep green and contains inclusions of plagioclase, titanite, apatite, and magnetite. About 10 per cent each of quartz and orthoclase occurs interstitially. Diopside appears as an accessory; also titanite, magnetite, and apatite.

The rock is a hornblende granodiorite.

Specimen 127. Collected from intrusive mass on north side of Hetta Lake, on the west side of the peninsula.

This rock is decidedly coarse grained, its texture being due in part to the distribution of biotite. Plagioclase, quartz, and orthoclase are the light-colored constituents. Many of the plagioclase crystals are 8 millimeters in length; the biotite scales are 4 millimeters in diameter, and the grains of quartz and orthoclase are somewhat smaller. In the thin section the average of the plagioclase is basic oligoclase or acidic andesine, and the crystals are decidedly zoned. This mineral constitutes about 60 per cent of the rock; quartz, 20 per cent; biotite, 15 per cent; orthoclase, 5 per cent. The accessory minerals are apatite, titanite, and magnetite.

This rock may be classed as a biotite granodiorite, though the specimen examined contains little orthoclase.

Specimen 677. Collected from center of small mass just north of Green Mountain.

A gray medium-grained granitoid rock which in the hand specimen shows as essential constituents plagioclase, orthoclase, quartz, hornblende, pyroxene, and subordinate magnetite and titanite. In the thin section the plagioclase is subhedral and shows pronounced zonal structure, the zones ranging in composition from oligoclase to central cores of labradorite, which are partly altered to epidote. The plagioclase, averaging basic oligoclase, constitutes about

40 per cent of the rock. Orthoclase, with some microcline, is abundant, constituting as much as 25 per cent of the slide studied. Common hornblende and uralite form 10 per cent of the rock; diopsidic augite, 10 per cent; titanite, 2 per cent; and apatite, 1 per cent. Interstitial quartz forms about 10 per cent of the rock.

But for its association this rock might be classed as a monzonite.

SYENITE.

The syenites are medium-grained light-gray to pale-pink rocks composed essentially of orthoclase and plagioclase (oligoclase variety) in different proportions, with hornblende as the principal dark mineral and pyroxene, magnetite, apatite, and titanite as accessories. The type of rock is determined largely by the amount of orthoclase present in the specimen. Where the proportion of orthoclase is much less than that of plagioclase the rock becomes a granodiorite or diorite. In the field it was not possible to recognize these distinctions.

The syenite forms a part of the batholithic masses occurring near its margin (specimens 626 and 121). It is also found in outlying dikes and in tongues branching from the main intrusive masses (specimen 128).

Specimen 626. Collected at point near contact of main granitic mass 1,000 feet east of Jumbo No. 4 mine at an elevation of 3,000 feet.

This is a medium to fine grained granitic rock containing much orthoclase, some pyroxene, plagioclase, and quartz. The visible accessories are pyrite, magnetite, and titanite. Geometric analysis under the microscope shows that the orthoclase constitutes 75 per cent of the mass of the rock. It occurs in subhedral, markedly perthitic crystals, nearly adjacent crystals being separated by a narrow band of quartz and plagioclase. Plagioclase, which composes 5 per cent of the rock, occurs in definitely bounded crystals, some of which form the nuclei of orthoclase crystals. The plagioclase is zoned and twinned according to both the Carlsbad and albite laws. It is essentially albite and oligoclase. The quartz is entirely interstitial and comprises about 10 per cent of the rock. The pyroxene, diopside, which amounts to 8 per cent, is anhedral. Well-formed apatite crystals are both included in and adjacent to the diopside.

The rock is a potash syenite.

Specimen 121. Collected from bluffs in creek just west of Lake Mellen at contact of main intrusive mass.

This is a grayish medium-grained granitoid rock, which in the hand specimen shows orthoclase, plagioclase, and hornblende. In thin section the zoned and subhedral plagioclase was determined to be albite and oligoclase, which constitute perhaps 50 per cent of the rock. The orthoclase is interstitial and amounts to 20 per cent; the hornblende, which occurs in rough prisms, forms 10 to 15 per cent; and the quartz about 5 per cent. The accessory minerals are pyroxene, magnetite, apatite, and titanite.

The rock is a hornblende syenite.

Specimen 128. Collected from dike rock cutting schists on east side of Hetta Lake.

This is a light-gray medium-grained rock of granitic and porphyritic texture. Orthoclase, some plagioclase, and quartz, together with small amounts of hornblende and titanite, are easily distinguished in the hand specimen. Plagioclase (albite and acidic oligoclase) composes about 50 per cent of the rock and occurs in large, regularly bounded crystals. Interstitial orthoclase constitutes 35 per cent of the rock. Quartz grains are plentiful, making up 15 per cent of the rock. Hornblende, diopside, biotite, magnetite, and titanite are the accessory minerals.

This rock is quartz syenite.

GABBRO.

The gabbros are made up of the more basic minerals, largely hornblende and pyroxene with a plagioclase feldspar, usually labradorite, and little or no quartz, and thus the percentage of silica is lower than in the other granitic intrusives. It is difficult in places to distinguish this rock from the diorite, as the two differ mainly in the variety of plagioclase feldspar they contain.

The gabbro constitutes some of the smaller batholithic masses occupying areas adjacent to the main granitic batholith (specimens 45 and 98). Another type of gabbro is found in dikes that cut the sedimentary rocks, but these dikes belong to another period of intrusion and are formed of a coarse phase of porphyrite or diabase. They are described under the heading "Dike rocks," on page 39. Dr. Merwin's petrographic descriptions follow:

Specimen 98. Collected from small intrusive mass three-fourths mile southwest of Hetta Mountain.

This is a dark-gray, coarse-grained rock with large hornblende prisms, grains of pyroxene, plagioclase, and magnetite. The dark crystals compose nearly 70 per cent of the rock. In thin section the hornblende is seen to be poikilitic, including crystals of plagioclase and pyroxene. In certain crystals an inner zone without inclusions has a greenish color. The other minerals are zonal plagioclase (labradorite), which compose 15 per cent of the rock; interstitial orthoclase, forming 7 per cent; and greenish pyroxene, slightly uralitized, forming 10 per cent. Accessories are magnetite, apatite, titanite, and some biotite.

The rock is a hornblende gabbro.

Specimen 45. Collected from intrusive mass on the south side of Portage Bay at an elevation of 500 feet.

A dark-gray, medium-grained rock containing long crystals of hornblende, which form the greater part of it, the remainder consisting of labradorite (20 per cent) and pyroxene (10 per cent). The accessory minerals are magnetite, apatite, titanite, and biotite.

The rock is a hornblende gabbro.

DISTRIBUTION OF THE IGNEOUS ROCKS.

The granitic intrusives constitute the core of the mountain mass that occupied the center of the area indicated on the map as composed of igneous intrusives. There is no evidence that this batholithic mass represents more than one period of intrusion, for it is uniform in character throughout, though the composition of the rock of which it is formed is variable. In the main Copper Mountain and Beaver Mountain masses at some distance from the contact the prevailing rock is uniform in grain and color and ranges in composition from granodiorite to diorite. Near the contact orthoclase occurs locally in amounts sufficiently large to make the rock a syenite. Representative specimens of the syenite were collected at a point one-half mile west of the summit of Copper Mountain, near the border of the Copper Mountain mass (specimen 626). The granodiorite, as is shown by specimens 127 and 133, forms the shore lines of Hetta Lake, Lake Mellen, and Summit Lake. On the west slope of Jumbo Basin, between Copper Mountain and Mount Jumbo, the diorite dominates (see specimens 643 and 662) and forms steep cliffs, locally called the Palisades, which show columnar structure due to jointing planes. The rocks of these cliffs are noteworthy, as the dark constituent of the diorite in their upper part is principally augite, whereas near the contact it is principally hornblende. The huge blocks of diorite that have fallen from these cliffs would make good building stone.

STRUCTURAL FEATURES.

The main structural features of the granitic intrusives observed on the surface exposures are shown on the areal geologic map, and their probable underground extensions are shown on geologic cross sections. The structural relation of the intruded rocks to the intrusives has already been mentioned. No pronounced structural breaks occur within the granitic intrusive masses. The joint planes follow two principal directions—northwest and northeast—and have deeply inclined to vertical dips. Near the borders of some of the masses are fractures filled with later intrusive dike rocks or quartz-feldspar veinlets. Faults of structural importance were not observed.

The joint planes and fractures near the borders of the batholithic masses are generally supposed to have been produced by forces developed when the magma was cooling.

The underground form or limit of the batholithic mass is shown by the attitude of its contact surfaces, which, except at a few places, dip under the intruded rocks at an angle of

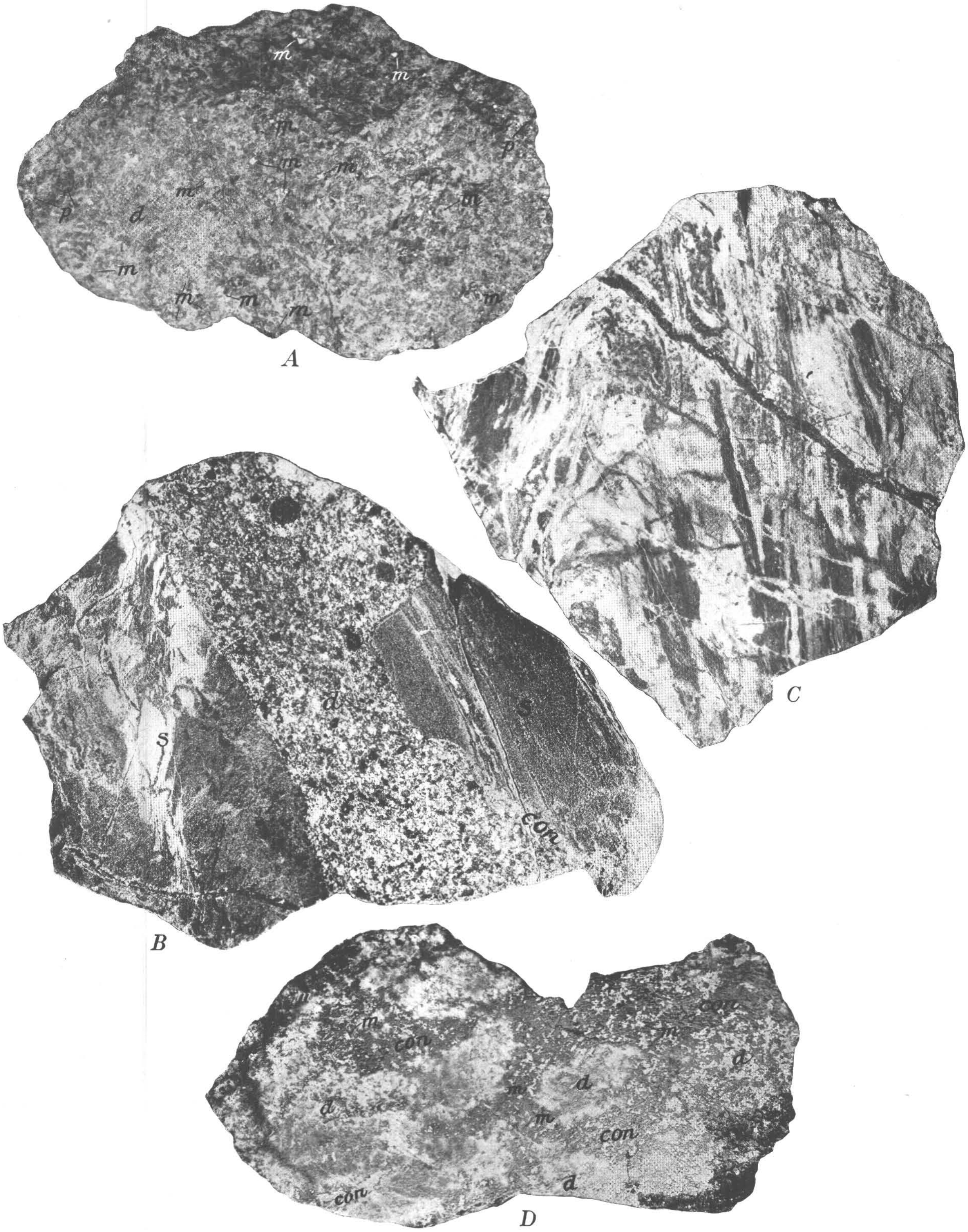
PLATE VII.

A. Altered diorite from the contact zone on Jumbo claim No. 4. The granitic texture is partly preserved though the feldspars are altered to scapolite and the amphiboles to diopside. Throughout the rock are small reflecting flakes of molybdenite, which are represented on the plate by the small white specks. *d*, Altered diorite; *m*, molybdenite; *p*, pyrite.

B. Fragment of schist from Jumbo claim No. 1, containing abundant pyrite, pyrrhotite, and magnetite. Such fragments of various sizes are included in a hornblende diorite. Many of the fragments are bordered by narrow rims (0.5 millimeter wide), which appear to be due to alteration by the diorite. *d*, Diorite; *s*, metamorphosed schist; *con*, contact of included schist, poorly defined, owing to partial absorption by igneous rock.

C. Metamorphosed schist adjacent to granite contact, which has been fractured and interstices filled with feldspar, quartz, and garnet. Specimen from Jumbo claim No. 1. The dark schistose bands contain plagioclase, quartz, and biotite. The dark vein contains diopside and plagioclase. The light patches are plagioclase with some quartz.

D. Altered diorite from contact zone on Jumbo claim No. 4. This specimen shows the diorite more altered than in *A*. Only patches of the granitic rock are preserved, surrounded by the contact rock, which is made up essentially of diopside and calcite with scattered grains of chalcopyrite. *d*, Altered diorite; *m*, molybdenite; *con*, contact rock containing scattered grains of chalcopyrite.



ROCKS FROM ZONE OF CONTACT OF SCHISTS AND DIORITE IN COPPER MOUNTAIN AREA.

about 70°. The relation of the intruded and intruding rocks is well exposed in many gulches that traverse the contact, the granitic rock forming the bed of the gulch and schist or limestone forming the banks. The structure of the intruded rock beds apparently had little influence on or control of the intrusion of the main masses, for the intrusion evidently determined the present position of the bedded rocks. The larger dimensions of most of the smaller granitic masses, however, lie in the bedding planes of the stratified rocks.

MARGINAL PHENOMENA.

The margins of the granitic intrusives show various noteworthy phenomena. The margin of the main granitic mass is in places irregular, forming deep bays, whereas at other points it forms nearly straight lines. Wide areas of the intruded schists are included within the intrusive mass and tongues of the intrusives branch out into the schists. At the margin of the intrusives there are many included fragments of the intruded rock of various sizes, ranging from minute pieces to masses several feet in diameter, and parts of some of these appear to be replaced by minerals that compose the intrusive. (See Pl. VII.) No faulting occurs at the margin of the intrusive or intruded rock and only small disconnected displacements in the rocks were noted. The intruded schistose beds are usually bent to conform with the contact of the intrusive masses, though in places they are much crinkled and squeezed or even brecciated. In general, however, it may be assumed that the intrusion of the granitic rocks took place at depths below the zone of faulting and fracturing, where the rocks were under pressure so great that they were very flexible. At certain points, however, a good example being in the lower tunnels on Jumbo No. 2 claim, the main intrusive mass has penetrated an area of brecciated schists, filling the interstices between the fragments and partly replacing them. Such phenomena are not uncommon at the contacts of most of the intrusive masses in southeastern Alaska. A change in the composition of the intrusive rock at points adjacent to ore-bearing zones is characteristic of the Copper Mountain area. Near the immediate contacts of the intrusive mass at these places diopside and orthoclase are the dominant mineral components, and scapolite or wollastonite occurs in abundance between the intrusives and the contact rock.

AGE.

It is evident that the granitic intrusives are more recent than the greenstones, which are the most recent bedded rocks in the Copper Mountain area. The intrusion therefore probably occurred in Mesozoic time. These granitic masses are similar in composition and character to those of the main Coast Range belt and were perhaps intruded during the same period of igneous invasion. Their age therefore is probably late Jurassic or early Cretaceous.

DIKE ROCKS.

PEGMATITES AND APLITES.

Dike rocks composed essentially of alkali, feldspar, and quartz occur in the neighborhood of the large granitic masses. Some of these rocks are coarse grained, containing large crystals of feldspar, and are classed as pegmatites; others are fine grained and rather uniform in texture and are classed as aplites. Together they form in places a network of small dikes and stringers within a zone of fractured schists, though they are more prominent as separate dikes traversing the granitic intrusives. The rock in some dikes appears to be composed essentially of quartz with very little feldspar and epidote and some garnet, and also magnetite and pyrite. These dike rocks are readily recognized by their light color, granular texture, and mode of occurrence.

The modes of formation of the aplites and pegmatites associated with the batholithic intrusives have been discussed by many geologists, and the intimate relation in origin between these dikes and the quartz veins and ore deposits has been pointed out by Spurr,[1] Lindgren,[2] and Barrell.[3] The general belief is that the pegmatite dikes at least are produced by aqueo-

[1] Spurr, J. E., Geology of the Yukon gold district, Alaska: U. S. Geol. Survey Eighteenth Ann. Rept., pt. 3, p. 311, 1898.
[2] Lindgren, Waldemar, The character and genesis of certain contact deposits: Am. Inst. Min. Eng. Trans., vol. 31, pp. 242-244, 1902.
[3] Barrell, Joseph, Geology of the Marysville mining district, Montana: U. S. Geol. Survey Prof. Paper 57, 1907.

igneous activity, through a process intermediate between injection of molten magma and precipitation from aqueous solutions.

The intimate association of the aplite and pegmatite dikes with the deposits in the contact zones and their relations to the ore deposits and the granitic intrusives are considered more fully under the heading "Genesis of the ores" (p. 102). The microscopic petrography of a specimen of the rock is described by Dr. H. E. Merwin as follows:

Specimen 622. Collected from a point on trail to Jumbo mine at an elevation of 700 feet. This rock is fine grained, almost white, and contains about 45 per cent each of orthoclase and plagioclase. The plagioclase varies in composition from Ab_4An_1 to Ab_2An_1. The rest of the rock mass is made up of 8 per cent of quartz and 2 per cent of hornblende, zircon, and other minerals. The rock, then, is an adamellite aplite.

PYROXENE-FELDSPAR DIKES.

Dikes or veins of rocks composed essentially of pyroxene and feldspar occur within the contact zones and branch out into the intrusive and intruded rocks. These rocks vary widely in composition, ranging from those containing 90 per cent of feldspar and 10 per cent of pyroxene to those containing 70 per cent of pyroxene and 30 per cent of feldspar. In some of them garnet and sulphide minerals occur both as primary mineral constituents and in cracks or veinlets as secondary minerals. The rocks have a medium to fine grained granular texture and are usually light to dark green in color, though where orthoclase dominates they are flesh-colored. These rocks cut the granitic intrusive rocks and were probably injected into fissures in the contact zone in a manner similar to the aplite dikes though at a somewhat later period. Their intersection by veinlets of garnet and the alteration of the feldspars in some of them to scapolite indicate that their formation antedates that of the ore deposits, though they may have been formed at about the same time, and their composition suggests that they were derived from the same underlying magma that produced the contact rock.

The microscopic petrography of the rock is described by Dr. H. E. Merwin as follows:

Specimen 11. Collected from 10-foot dike in contact zone one-half mile southwest of Copper Mountain at an elevation of 2,500 feet.

This rock occurs in small dikes or veins which are confined to the borders of the intrusive masses and cut both the intrusive rock and the contact rock. It also occurs in irregular masses at the margins of the granitic intrusives.

The rock is of fine-grained granitic texture, flesh-colored, and in the hand specimen shows patches of light-green pyroxene in a groundmass made up of irregular grains and plates of orthoclase. Under the microscope orthoclase and diopside are shown to be the chief constituents; albite, titanite, and apatite are present as accessories and compose about 1 per cent of the rock mass. The orthoclase constitutes about 90 per cent of the rock, and occurs in both anhedral grains and in subhedral plates showing Carlsbad twinning. The pyroxene is subhedral and is colorless to pale green. Optically, it is diopside with a probable slight mixture of ægirite in the greenish grains. Its distribution is somewhat irregular. This rock may be called a diopside orthoclasite.

An analysis of the rock made by Chase Palmer and calculations from the analysis by the methods of the quantitative system show the following chemical and mineralogic (normative) composition:

Chemical composition of diopside orthoclasite.

SiO_2	62.03	K_2O	12.38
Al_2O_3	16.39	H_2O	.24
Fe_2O_3	.72	H_2O+	.61
FeO	.86	TiO_2	.53
MgO	1.60	P_2O_5	.13
CaO	3.60		
Na_2O	1.08		100.17

Mineral composition of diopside orthoclasite.

Quartz	1.26	Magnetite	0.93
Orthoclase	73.39	Apatite	.34
Albite	9.43	Ilmenite	1.06
Anorthite	3.06	(Water)	.85
Diopside	8.89		
Wollastonite	1.04		100.25

The notable characteristics of the rock are its high orthoclase and low quartz. The normative orthoclase is higher than for any rock in Washington's tables,[1] and the actual orthoclase (which includes the normative albite and anorthite in solid solution) is higher still. A quartz-orthoclasite listed on page 143 of Washington's tables contain about the same amount of normative orthoclase. The rock belongs in the rang nordmarkare of the quantitative system, but its high potash content places it in a hitherto unrepresented subrang—the perpotassic—which may properly be called hettose, from the occurrence of the rock on the shores of Hetta Inlet.

Specimen 615. Collected from 6-foot dike cutting diorite in long tunnel 500 feet from mouth of New York claim.

This is a greenish holocrystalline rock consisting of a light-colored pyroxene (about 70 per cent) and plagioclase feldspar which is largely altered to scapolite. Much of the scapolite is in individual crystals more than a hundred times as large as the feldspar crystals replaced, giving the rock a poikilitic appearance. Euhedral crystals of pyrite and much chalcopyrite and pyrrhotite are scattered through the rock. The last two minerals appear to have been introduced at the same time as garnet and epidote, which fill many joints in the rock. What appears to have been an earlier set of minute veins filled with feldspar are now parts of scapolite crystals. The pyroxene occurs mostly in small rounded grains, but also in larger, irregular crystals. This mineral is unaltered.

Specimen 623. Collected from 4-foot dike cutting diorite and contact rock just below open cut on New York claim.

A fine-grained rock which in the hand specimen is greenish with irregular bright pink blotches. Under the microscope the green color is found to be due to a pyroxene which occurs in rounded grains and irregular crystals having a very fresh appearance. The pink masses are altered feldspar. Phenocrysts of acid labradorite have been altered to very fine grained aggregates. The alteration has extended around the phenocrysts into the plagioclase of the groundmass, thus making the pink areas irregular. The predominant mineral of the aggregates, though not occurring in grains large enough for positive identification, is probably a light-colored mica. In the slide it resembles the scapolite of other altered rocks of the district, but it has positive elongation parallel to the cleavage. Examined in powdered form, its refractive indices were found to be 1.56 to 1.59. Other minerals in the alteration aggregates are calcite and a mineral having moderate to weak double refraction and refractive index of about 1.69—probably zoisite.

Specimen 658. Collected from dike on Jumbo No. 4 claim, upper surface workings.

A fine-grained granitic rock containing about 50 per cent each of basic plagioclase and a pale-green pyroxene. The minerals are very fresh, even where cut by numerous veins of garnet. A few grains of the pyroxene are altered to a more highly refracting mineral showing interference colors like zoisite. This alteration seems to have taken place before the garnet veins came in. These are sharply bounded by fracture surfaces.

PORPHYRIES.

Porphyritic dike rocks are common within the area and were observed principally along the shores and in the streams that traverse the schists and limestones (probably largely Carboniferous) as well as the later greenstones. They cut the granitic intrusives and the aplite dikes and are therefore of more recent intrusion. The porphyritic dikes are generally 5 to 50 feet

[1] Washington, H. S., Chemical analyses of igneous rocks published from 1884 to 1900, with a critical discussion of the character and use of analyses: U. S. Geol. Survey Prof. Paper 14, 1903.

wide but average about 12 feet in width. The rock consists of a finely crystalline groundmass with phenocrysts of basic plagioclase and hornblende.

The microscopic petrography of the rock is described by Dr. H. E. Merwin as follows:

Specimen 59. Collected from south shore of Hetta Inlet 1 mile west of Gould Island.

This is a light greenish-gray fine-grained porphyritic rock containing phenocrysts of plagioclase. In the thin section the plagioclase (acidic andesine) forms 75 per cent of the rock, a light-green slightly pleochroic hornblende, in irregular crystals and scattered grains, forms 15 to 20 per cent, and magnetite forms 5 to 10 per cent. Titanite, epidote, and calcite occur in very small amounts. The groundmass shows a decided parallel arrangement of the plagioclase crystals due to flow structure.

The rock is a diorite porphyry.

Specimen 104. Collected from a dike 30 feet wide near the ore deposit on a ridge on the west slope of Hetta Mountain.

This is a medium to fine grained porphyritic rock containing abundant plagioclase and scattered phenocrysts of hornblende. Under the microscope the phenocrysts of plagioclase, approximately andesine in formation, appear to be well-bounded crystals, zoned and twinned. The hornblende occurs in ragged prisms, shows pleochroism from light yellow to light green, and is partly chloritized. The groundmass is made up of a finely granular plagioclase that exhibits no distinct twinning or zoning but shows undular extinction. Magnetite, titanite, and apatite are accessory constituents.

The rock is a porphyry.

Specimen 73. Collected from dike 6 feet wide cutting schists on the west shore of Hetta Inlet opposite Jumbo Island.

This is a fine-grained porphyritic rock with long, slender phenocrysts of hornblende up to 2 centimeters in length, having a parallel arrangement, probably due to flowage in the magma before crystallization. Many of these crystals show effects of magmatic corrosion. The hornblende, which constitutes 35 per cent of the rock, is pleochroic, ranging from light yellow to dark yellow-green. A colorless pyroxene occurs in irregular grains in small amount—about 3 per cent. The feldspar (andesine to acidic labradorite) occurs in very small poikilitic crystals which are usually not twinned. Alteration to chlorite and calcite has begun. The feldspar, including a plagioclase of similar composition in the groundmass, constitutes 45 per cent of the rock mass. Magnetite is abundant, forming about 10 per cent of the rock.

The rock is a diorite porphyry or lamprophyre.

LAMPROPHYRE.

Dikes of lamprophyre, most of them 1 foot to 6 feet wide, cut the rocks near the granitic contacts. (See Pl. VI, *B*, p. 32.) They are generally much altered and in places are faulted, and no older intrusive rock was noted in the area. They are older than the ore deposits or the granitic intrusives. The dikes in the contact zone are broken and have been here and there much altered and in part replaced by minerals of the contact rock. The rock is black, fine grained, and of porphyritic texture, and contains phenocrysts of pyroxene, mostly uralitized. Plagioclase and uralite compose the groundmass. The accessory minerals are magnetite and titanite.

Dr. Merwin describes the microscopic structure of the rock as follows:

Specimen 651. Collected from open cut in gulch on Jumbo No. 4 claim, Copper Mountain.

This rock is greenish black, of aphanitic texture, and under the microscope shows about 70 per cent of amphibole, 20 per cent of altered plagioclase, 5 per cent of biotite, and some pyrite, titanite, and magnetite. It is traversed by veinlets that vary from mere threads to ribbons several inches wide, formed of garnet and diopside. The rock near these veinlets and at the contacts has assumed a lighter color, owing to the bleaching of the hornblende.

The rock is an altered lamprophyre.

Specimen 658. Collected from dike cutting limestone at mine workings in gulch on Jumbo No. 4 claim.

A fine-grained to porphyritic greenish-black rock containing altered labradorite (60 per cent) showing zonal structure. The groundmass contains also chlorite and magnetite and secondary veinlets of diopside and garnet. Near the contacts of the dike and adjacent to the veinlets the rock is altered to a lighter green.

The rock is an altered lamprophyre.

DIABASE.

Many dikes of diabase were noted along the shores of Hetta Inlet. They cut the greenstones and here and there the older schists and limestones. They are generally from 2 to 10 feet wide, and most of them strike northeastward across the stratification of the country rock. The diabase is essentially a plagioclase-augite rock of diabasic texture, dark-green color, and medium fine grain. In certain places coarse-grained dikes of this rock, the largest 50 feet wide, resemble gabbro, though they still retain a diabasic texture.

These diabase dikes are evidently younger than the granitic intrusives and the ore deposits, for they cut the contact deposits on the Green Monster claim, as well as those in the greenstone schists on the Corbin claim. They have no genetic relation to the ore deposits.

Dr. Merwin's descriptions follow.

Specimen 58. Collected from point 1½ miles north of Jumbo Landing, on east side of Hetta Inlet.

The rock is of porphyritic texture. Large crystals having the outlines of augite form the phenocrysts. This augite and that appearing in the groundmass are entirely uralitized. Feldspar occurs in small crystals. Very many slender prisms of apatite, included by the feldspar, and minute crystals of titanite are the principal accessory minerals. The rock contains 70 per cent of uralite, 25 per cent of labradorite, and 5 per cent of accessory minerals.

The rock is an altered diabase.

Specimen 48. Collected from 15-foot dike cutting schists on south shore of Hetta Inlet, 1 mile east of Gould Island.

This rock is medium to fine grained and of porphyritic texture. The phenocrysts are 4 to 7 millimeters in length and consist of plagioclase and hornblende. The plagioclase (acidic labradorite) is twinned after the Carlsbad and albite laws and makes up about half the volume of the rock. So much feldspar is inclosed on the irregular margins of the hornblende crystals as to give them a poikilitic appearance. The biotite, which constitutes about 5 per cent of the rock, occurs in very fine scales, scattered rather evenly. Magnetite and pyrite occur in small grains in the groundmass.

The rock is a diabase or, more specifically, a hornblende dolerite.

GEOLOGIC HISTORY.

The record of the periods of sedimentary deposition and igneous intrusion represented in the Copper Mountain area is defined only by structural relations, not by paleontologic evidence. The oldest sedimentary strata are the schists and limestones, which are probably largely of Carboniferous age, an inference based on their marked similarity to the metamorphic schists of the mainland belt, where included limestone beds contain Carboniferous fossils, though they probably include some strata of Mesozoic age. This metamorphic series is made up of a great thickness of bedded rocks, originally argillaceous, calcareous, and siliceous shales and sandstones, and may include several conformable formations. More recent in age are the greenstones, which overlie the schists and limestones with apparent conformity. They are characterized by their content of volcanic material, indicating an extensive period of volcanic eruption, which assumed the form of tuffaceous outbursts rather than that of lava flows. Evidence from adjacent areas indicates that these rocks were deposited in Mesozoic time. Later all these bedded rocks were subjected to mountain-building forces, which induced metamorphism and upturned the stratified rocks within the area. During this period basaltic dikes or lamprophyres were injected along fracture planes in the rocks and were also subjected to faulting and flexuring due to the mountain-building forces.

The most important geologic event in the region was the granitic intrusion, which continued during a long period and by which a large quantity of igneous material was carried from an underlying magma into the overlying sedimentary rocks. The main granitic intrusion is regarded as Mesozoic, probably late Jurassic or early Cretaceous, and conforms in age to the Coast Range intrusions. The intrusion of the granitic masses was followed by the injection of pegmatite and aplite dikes, which are regarded as differentiation products of the granitic magmas.

The next important event was the deposition of ores at the contacts of the intrusive masses—an event that closely followed the injection of the pegmatite and aplite dikes. The ore deposits were accompanied by large masses of garnet-epidote-diopside rock, which, like the ore deposits, are believed to have been derived from the underlying granitic magma. The most recent rocks in the area are the porphyritic and basalt dikes, which are fairly abundant. These intrusions probably occurred in Mesozoic time. The record of the more recent geologic periods, though not found in the rock formations, is represented in the present topographic features, which have already been described.

COPPER ORES OF THE COPPER MOUNTAIN AREA.

GENERAL CHARACTER.

The Copper Mountain area presents exceptional opportunities for a study of the relations between the igneous intrusives, the ore deposits, and the occurrence of minerals attributable to metamorphic actions, but as only a few months were spent in the field, and as an exhaustive study of the minerals and rock specimens collected has not been made, the problems presented can be only briefly considered.

In order not to confuse observed facts with hypotheses regarding ore genesis, metamorphism, and like phenomena, only the observed facts will be stated here and the more theoretical questions will be discussed under the heading "Genesis of the ores" (p. 102). The principal metal in all the ore deposits in the area is copper, gold and silver appearing in minor quantities. Considerable bodies of magnetite are associated with some of the copper ores, but these have not yet been mined except for their copper content. Zinc and lead are present in some of the ores but not in commercial amounts. The deposits consist mostly of primary minerals, the ores not having been enriched by the action of surface waters.

GEOGRAPHIC AND GEOLOGIC DISTRIBUTION.

The distribution of the ore deposits is clearly shown on the geologic map of the Copper Mountain area (Pl. V, p. 30). This map indicates the location of ore bodies on which some development work has been done and which are described under the heading "Mining in the Copper Mountain area" (p. 53).

The relation of these deposits to the geology, and especially to the granitic intrusives, is best seen by reference to the map. A striking fact is that most of the deposits are at the contacts of the granitic intrusives with the limestones and schists, especially in the places where the line of contact forms strong reentrants. Other deposits occur in the greenstones at a considerable distance from the intrusive contacts.

TYPES OF ORE DEPOSITS.

The following three types of ore deposits have been recognized in the Copper Mountain area:

Contact deposits, occurring at the contact of the granitic rocks and the schists and limestones; containing chalcopyrite associated with pyrite and magnetite or pyrrhotite in a gangue of garnet, pyroxene, amphibole, epidote, and other metamorphic minerals; also calcite and some quartz.

Vein deposits, occupying fissures or shear zones in the greenstones and containing shoots of massive sulphide ore composed of chalcopyrite and pyrite, with some sphalerite, in a quartz-calcite and chlorite gangue.

Disseminated deposits, consisting of mineralized schistose beds in the older schists. Chalcopyrite and pyrite are finely disseminated through these beds and are accompanied by quartz and calcite veinlets.

The contact deposits are the most important commercially and of greatest interest geologically and are therefore considered at length in this report. The vein deposits are less important, though at two mines they have been developed to a considerable extent. The disseminated deposits are at present of little importance and have been only slightly developed, for their low metal content prevents their exploitation.

CONTACT DEPOSITS.

THE CONTACT ZONE.

The contact deposits occur within the contact rock that occupies a zone surrounding the granitic intrusive masses. This contact rock is made up of various combinations of minerals, its principal components being garnet, amphibole, pyroxene, epidote, and calcite, which occur together in separate crystalline groups or more often as a felsite-like mass. The contact rock occurs irregularly around the contact zone; in some places it is entirely lacking and in others it has a surface width of several hundred feet. Its surface width at many points is much greater than its actual width, especially on hillsides where the dip of the intrusive rock surface is only slightly steeper than the slope. Its usual width, however, ranges from 25 to 250 feet. At certain localities the intrusive and intruded rocks are in direct contact with each other, the minerals composing the contact rock being notably absent.

In some places dikes or veins of the contact rock branch out into the limestones and schists and occupy fissures in the granitic intrusive. Few of these veins are more than 1,000 feet long. Large areas of the contact rock occur just within the granitic intrusive and on the surface appear to be surrounded by the granitic rock. These areas may represent wide fractures within the intrusive which have been filled with the contact rock, or they may be masses of the intruded rocks which have been replaced by the contact rock.

THE ORE IN THE CONTACT ZONE.

Types of contact deposits.—The ore within the contact zone occurs in irregular masses that range in diameter from 10 to 100 feet. These masses generally occur on one or the other side of the contact zone; they are rarely found in the center.

The contact deposits may be divided into two classes, according to their mineral composition. In certain deposits chalcopyrite ore is associated with masses of magnetite and these are distinguished as the chalcopyrite-magnetite type. In other deposits chalcopyrite is associated with pyrrhotite and these are distinguished as the chalcopyrite-pyrrhotite type.

Chalcopyrite-magnetite type.—The chalcopyrite in deposits of the chalcopyrite-magnetite type is usually disseminated and seldom in rich masses. The gangue minerals are garnet, amphibole, and pyroxene, and the deposits are compact and finely crystallized. Deposits of this type were noted only between the granitic intrusive and the contact rock, as on the north side of Jumbo Basin, where erosion has removed the overlying contact rock and the magnetite deposit exposed resembles a shell or coating on the surface of the granitic intrusive. This deposit is from 5 to 15 feet thick and over 100 feet wide. At its contact with the granitic rock, which is the footwall, the ore, with the contact minerals, grades into the intrusive mass, the minerals of which are replaced by garnet, epidote, calcite, etc. This zone of gradual replacement between the contact rock and the intrusive is often many feet wide. On the hangingwall side is the contact rock, which is overlain by metamorphic schists, and here also there is no line of demarcation between the two rocks but a gradual change due to replacement of the schists by the contact minerals.

Chalcopyrite-pyrrhotite type.—In this type chalcopyrite and pyrrhotite, the two principal sulphide minerals, occur associated together and also in separate masses. The gangue minerals are garnet, diopside, epidote, calcite, and rarely quartz. (See Pl. VIII.) Pyrite is present but no magnetite. As a rule these minerals are coarsely crystallized, calcite filling the interstices and small crystal druses being common. These features of crystal occurrence are more clearly evident in rock adjacent to the ore bodies and help to indicate the location of the masses of sulphide ore. Farther away from the ore bodies the contact rock is more compact and even felsitic in aspect. These features of the ore deposits are clearly shown in the mine tunnels on Jumbo No. 4 claim at the head of Jumbo Basin. Deposits of the chalcopyrite-pyrrhotite type are most likely to be found where limestone occurs at the contact or on the contact rock adjacent to the limestone. They are also found at the contacts of the granitic rocks with the contact rock and in masses of contact rock that lie within the granitic intrusives. One of the most important masses lies within a vein of contact rock that branches out into the limestone beds, away from the contact zone.

Relation of intruded rocks to contact deposits.—The influence of the different rock strata at the contacts of the intrusive masses on the nature of the contact deposits is noteworthy, as the character of the intruded strata determines to some extent the location of the ore masses. However, these rock beds have not entered into nor do they determine in large measure the composition of the contact rock which incloses the deposits, as has been pointed out in reports on other districts where contact deposits occur. Where limestone forms the wall rock the effect has been to limit the ore deposits and the contact rock rather abruptly; in other words, the minerals of the contact deposits do not penetrate the limestone wall. The limestones at these points show no bedding planes, are very pure in composition, are recrystallized to a fine white marble, and were apparently impervious to the mineralizing solutions. Large rounded detached masses of the limestone walls occur within the contact rock, and the edges of these masses and those of the limestone walls indicate that this rock has been dissolved or eaten away by the mineral solutions that deposited the ores and the contact rock. As many of the richer ore masses occur where the limestone is present, the limestone may have assisted in precipitating the sulphide minerals. This question is discussed under the heading "Genesis of the ores" (p. 102).

Where the schistose rocks form the walls of the contact deposits the mineralization is less concentrated, the contact rock shows less tendency to crystallize, and the minerals show less tendency to segregate. The sulphide ores are more disseminated in the contact rock, and the contact minerals, including the sulphides, penetrate the schists for some distance from the contact. Angular fragments of the schistose rocks are in places included in the contact rock, and veins of the latter extend along fissures and between the schist strata for some distance away from the contact zone. The schists that show this replacement by the minerals composing the contact rock are essentially calcareous, whereas the more siliceous rocks apparently suffered little change during the mineralization.

Location of minable ore.—The productive ore masses found in the contact zone are confined chiefly to Jumbo Basin and the Copper Mountain ridge just above Jumbo Basin. (See Pl. III, *B*, p. 28.) These deposits are of the chalcopyrite-pyrrhotite type. Large deposits of the chalcopyrite-magnetite type occur on the north side of the Jumbo Basin and are said to contain sufficient copper to make them minable, but they are far away from transportation lines.

Other ore masses have been prospected at many points around the granitic intrusive masses, but most of them are not convenient to lines of transportation and it has been difficult to do development work on them, so that on most of the locations little has been done but the annual assessment work.

VEIN DEPOSITS.

Most of the vein deposits are in the schists, with which they generally coincide in strike and dip. These veins are persistent in length and depth, and the ore in them occurs in shoots of massive sulphides, essentially chalcopyrite, pyrite, and some sphalerite, associated with calcite, quartz, and chlorite. These shoots are 1 foot to 4 feet wide, 20 to 80 feet long, and at one locality have been developed to a depth of more than 100 feet. Those parts of the veins that carry no ore are well marked by gouge containing pyrite and veinlets of quartz and calcite.

The altered schist near the veins is pale green to white, the color of the rock grading away from the veins into the general dark-green color of the unaltered schist. Veins of this type have been developed at the Corbin and Red Wing mines, both situated near sea level along the east shore of Hetta Inlet. These deposits will be described in detail under the heading "Mining in the Copper Mountain area" (p. 53).

DISSEMINATED DEPOSITS.

At a few points in the Copper Mountain area mineralized schists carrying small amounts of copper and gold have been found, and on certain of these deposits small developments have been made. Some of these deposits extend for long distances and range in width from 5 to 25 feet. They are intercalated in the older schists and some of them are more or less fissured, the fissures carrying quartz and calcite. The principal deposits of this type occur in the lower part of Jumbo Basin at an elevation of about 300 feet. Because of their low copper content they have not been extensively explored and have not yet become productive.

MINERALS OF THE DEPOSITS.[1]

SCOPE OF THE DISCUSSION.

The minerals composing the ore deposits in the Copper Mountain area are doubtless of less interest to the miner than the ore bodies themselves, but the mineralogy of the ores is important to the geologist and may assist him materially in determining the conditions under which the deposits were formed. Here, however, only brief mention will be made of the ore and gangue minerals of the deposits. Detailed descriptions of the essential features of each mineral may be found in any textbook on mineralogy. The primary ore minerals are described first, then the secondary ore minerals, and then the gangue minerals and other minerals in the contact zones.

PRIMARY ORE MINERALS.

Chalcopyrite.—The principal ore in the Copper Mountain district is chalcopyrite, the sulphide of copper and iron, which occurs in the contact deposits chiefly in masses more or less mixed with pyrite and pyrrhotite (see Pl. VIII, *E*), in the vein deposits in rich though relatively small ore shoots, and in the disseminated deposits in finely scattered particles, generally not in amount sufficient to form an ore. Chalcopyrite is readily distinguished from the iron-sulphide minerals by its brass-yellow color and by the fact that it is softer and powders readily under the knife blade. In the contact deposits it is associated with pyrite, hematite, and, more rarely, molybdenite, the gangue minerals being principally garnet, quartz, calcite, pyroxene, amphibole, and epidote; in the vein deposits it is accompanied by sphalerite or galena. At the Jumbo mine chalcopyrite and garnet fill spaces between interlacing crystals of scapolite. In the contact deposits chalcopyrite is in places well crystallized in druses, though in the other deposits no crystals were observed. The other sulphides of copper—namely, bornite and chalcocite—were not noted in the district.

Pyrite.—Pyrite, a sulphide of iron, occurs in all the ore deposits and is scattered through the metamorphic rocks of the region and finely disseminated in the igneous rocks. It has not been found in masses large enough to make it valuable as an ore of sulphur. The copper ores contain large percentages of pyrite, which carries gold in amounts ranging from $1 to $2 to the ton. The pyrite disseminated in the schists also contains gold.

Pyrrhotite.—The occurrence of pyrrhotite is similar to that of pyrite, though it is less widely distributed. It is a sulphide of iron containing less sulphur than pyrite and is readily distinguished by its darker bronzelike color and its magnetic properties. It occurs in large masses in the contact deposits, but was not noted in the vein deposits. (See Pl. VIII.)

Pyrrhotite ores containing sufficient nickel to make a nickel ore occur at Sudbury, Canada, and at several foreign localities, notably at Kongsberg, Norway. Because of this association

[1] The writer is indebted to Dr. H. E. Merwin, of the Geophysical Laboratory of the Carnegie Institution of Washington, for a detailed study of the minerals collected from this region. The results of Dr. Merwin's investigations are given in the mineral descriptions.

PLATE VIII.

A. Ore containing irregular groups of pyrite crystals and chalcopyrite in a gangue of calcite, diopside, and garnet. Specimen taken near granite contact, Jumbo claim No. 4. *c*, Calcite; *ch*, chalcopyrite; *dc*, diopside, calcite; *g*, essentially garnet; *p*, pyrite.

B. Scapolite. This mineral occurs in masses of radiating crystals in druses. Specimen from upper workings on Jumbo claim No. 4.

C. Specimen showing contact of limestone with contact rock. At the contact and adjacent to it in the limestone a very light colored amphibole has been developed. The main mass of dark rock is diopside and calcite, but in the immediate vicinity of the ore and to a less degree in other parts of the mass a dark amphibole appears. The limestone is rather pure. *c*, Calcite; *ch*, chalcopyrite; *ag*, calcite amphibolite, garnet; *dg*, diopside, garnet.

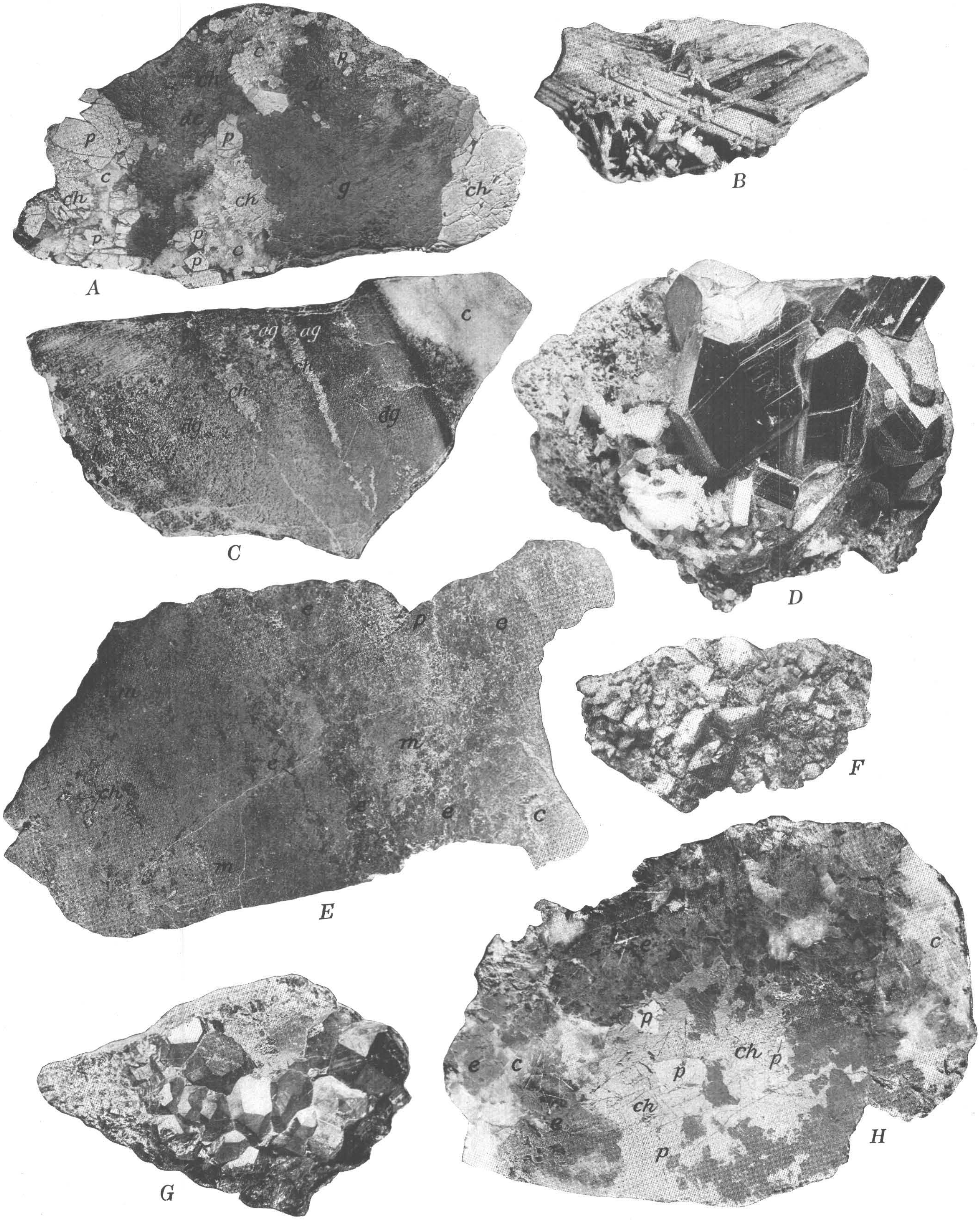
D. Group of epidote crystals and cluster of quartz crystals on contact rock. Specimen from west slope of Green Monster Mountain near summit.

E. Metallic minerals (magnetite, pyrite, and chalcopyrite) associated with minerals of the contact rock, principally epidote and calcite. Specimen from Jumbo claim No. 1. *c*, Calcite; *ch*, chalcopyrite; *e*, epidote; *m*, magnetite; *p*, pyrite.

F. Adularia showing prismatic crystals with slightly curved faces. Specimen from north side of Green Monster Mountain near summit.

G. Garnet. These crystals are smaller and of a more uniform color than the garnet which predominates in the contact deposits. From New York claim, Copper Mountain group.

H. Crystals of pyrite inclosed in pyrrhotite. The gangue consists almost entirely of calcite, which is tinged greenish in places by inclusions of minute diopside crystals. From Jumbo claim No. 4 near limestone contact. *c*, Calcite; *ch*, chalcopyrite; *e*, epidote; *p*, pyrite.



ROCKS AND MINERALS FROM COPPER MOUNTAIN AREA.

and because masses of this mineral at one locality were reported to contain large amounts of cobalt, samples of nearly pure pyrrhotite were taken at two different localities and submitted for determination of their content of nickel, cobalt, platinum, and gold, with the following results:

Assays for rare metals in pyrrhotite ore.

[Assays made by George Steiger, United States Geological Survey.]

	Nickel.	Cobalt.	Platinum.	Gold.
	Per cent.			
No. 5. Sultana claim, north side of Hetta Inlet, Ketchikan district, Alaska	0.1-0.2	Trace.	None.	None.
No. 6. Iron-Crown claim, Copper Mountain, Ketchikan district, Alaska	.1- .2	Trace.	None.	None.

Sphalerite.—The mineral commonly called zinc blende, the sulphide of zinc (sphalerite), containing 67 per cent zinc, having generally a dark color and a semimetallic luster and distinguished by its light-brown powder, is found in the vein deposits associated with chalcopyrite and galena, quartz and calcite being the gangue minerals. It is not known to occur in quantities sufficiently large to make a zinc ore.

Galena.—Galena, the sulphide of lead, occurs in small amounts in vein deposits on Gould Island, associated with chalcopyrite and sphalerite, with calcite and quartz as gangue minerals.

Molybdenite.—The rare mineral molybdenite, the sulphide of molybdenum, occurs in the contact deposits, usually in small flakes in the contact rock or in the altered granitic rock near these deposits. At the Jumbo No. 4 claim it is associated with garnet, calcite, diopside, and chalcopyrite. It is a soft, flaky mineral with metallic luster resembling graphite but having a bluer tinge. It is not found in the Copper Mountain region in commercial quantities. (See Pl. VII, *A*.)

Magnetite.—Magnetite, the magnetic oxide of iron, occurs in large masses at the intrusive contacts, associated with the copper ores. Such masses are common in Jumbo Basin, where they have been largely developed. (See Pl. VIII, *E*.)

Minute grains and octahedral crystals of magnetite occur with the ferromagnesian silicates and in the groundmass of the greenstone schists and some of the intrusive rocks. Magnetite was also observed in certain pegmatite or aplite dikes and in quartz veins, with calcite, pyrite, and chalcopyrite.

The presence of chalcopyrite in these magnetite masses makes them important copper-bearing deposits and their high iron content gives them value to the smelters as a flux in the reduction of copper.

The occurrence of the magnetite in association with chalcopyrite, pyrrhotite, and pyrite in the contact deposits shows that it was deposited under conditions similar to those under which these sulphides were formed. In the intrusives, on the other hand, magnetite is apparently an original constituent.

Specularite.—Nearly all the contact deposits contain small amounts of specularite or micaceous hematite, an anhydrous oxide of iron. Its association indicates that it was deposited at the same time as the copper ores and under similar conditions. Flat crystals of specularite one-half inch across, showing numerous rhombohedral faces around the edges, were found.

SECONDARY ORE MINERALS.

Limonite.—The hydrous oxide of iron, limonite, is found principally at the surface outcrops of the ore deposits, having been formed largely from the decomposition of the iron sulphides. It occurs principally in association with the copper carbonate ores on the Copper Mountain ridge, where it extends to a considerable depth below the surface. In general these oxidized or secondary ores form only a shallow capping on the sulphide ore deposits.

Malachite.—The green mineral malachite, the basic carbonate of copper, is found in small amounts at the outcrops of the copper deposits, usually where limestone forms the inclosing rock. It occurs principally in small masses in a garnetiferous and limestone gangue on Copper Mountain, where surface alteration has been extensive. It generally forms narrow seams or veinlets and incrustation or coating on the sulphide ores and is associated with limonite, chrysocolla, and small amounts of cuprite. Its high copper content and the facility with which it may be smelted make it a most desirable copper ore, but no large deposits of it have been found in the district.

Azurite.—Azurite, like malachite, is a carbonate of copper, but may be distinguished by its deep-blue color. It was observed in small amounts only and invariably in association with malachite as a surficial alteration product of the sulphide copper ores.

Chrysocolla.—The hydrous silicate of copper, chrysocolla, like malachite and azurite, has been found in notable quantities only at the Copper Mountain mine, where it is apparently confined to the surface workings and is of minor importance.

Cuprite.—Cuprite, a red oxide of copper resulting from the oxidation of the sulphide ores, occurs in small amounts at the surface workings of the Copper Mountain mine.

Copper.—Native copper was observed at the Jumbo Basin mines on Copper Mountain and at the Houghton group. It occurs as thin flakes in cracks or gouge seams at the outcrops of the ore deposits. It is probably the result of deoxidation of cuprite and is therefore secondary.

GANGUE MINERALS.

Garnet.—Garnet is the principal gangue mineral of the contact deposits and is confined chiefly to the intrusive contacts. Though it commonly occurs in massive form, resembling a felsitic rock, it appears also in crystal aggregates associated with epidote, quartz, and other silicates. (See Pl. VIII, *G.*) The garnet found is mostly of the variety andradite, but includes some grossularite. The separate crystals are principally dodecahedrons with trapezohedral faces slightly developed. In cross section they show concentric structure resembling banded agate, being made up of yellow to pale-green and red bands which represent slight changes in composition occurring during the growth of the crystals. Partings parallel to the dodecahedral faces between zones of different colors indicate an interruption in growth, and some of the partings contain thin layers of calcite. (See Pl. VIII, *G.*) The crystals range in size from a few millimeters to 5 centimeters and many of them are twinned. In color the garnets differ greatly, presenting several shades of green, yellow, and brown. The crystal faces show subadamantine luster, though the masses have a rather greasy luster. To determine the variety of this massive garnet samples were submitted for analysis. The results of these analyses and of analyses of garnet from other localities are presented in the following table:

Analyses of garnet occurring in contact deposits.

	1	2	3	4	5	6
SiO_2	35.18	36.26	37.79	37.15	35.5	40.0
Al_2O_3	5.15	.78	11.97	6.98		22.7
Fe_2O_3	25.05	32.43	15.77	19.40	31.5	
FeO	.40	.32	1.31			
MgO	.09	None.	.37			
CaO	33.36	29.67	32.57	32.44	33	37.3
H_2O	.42	.57	.09			
TiO_2	None.	None.				
$CaCO_3$		None.		4.20		
P_2O_5		.06				
MnO		.27	.31			
	99.65	99.67	100.18	100.60	100	100

1. Garnet rock, Jumbo mine, Prince of Wales Island, Alaska. Analyst, W. T. Schaller.
2. Garnet, Morenci, Ariz., U. S. Geol. Survey Prof. Paper 43, p. 134. Analyst, George Steiger.
3. Massive brown garnet, White Knob, Idaho, Econ. Geology, vol. 2, No. 1, p. 7.
4. Garnet, San Jose, Mexico., Am. Inst. Min. Eng. Trans., vol. 36, p. 92.
5. Typical composition of andradite.
6. Typical composition of grossularite.

The above analyses show that the larger percentage of the garnet associated with contact deposits is andradite and not grossularite.

The masses of garnet are confined principally to the contacts of limestone of nearly pure calcium carbonate, with igneous rocks, suggesting that a vast amount of foreign material has been introduced along the intrusive contacts. Where the intrusives invade a quartzite country rock the garnet forms bands in the siliceous beds, many of the bands extending thousands of feet from the contact. At Copper Mountain the garnet forms a massive belt, 25 to 150 feet wide, between the intrusive diorite and the limestone country rock and occurs in veins crosscutting the limestone beds and penetrating the intrusive rock. The belt includes small masses of chalcopyrite, magnetite, and pyrrhotite, which constitute the copper ores.

Besides occurring disseminated in the contact deposits and in veins, garnet is a primary mineral in some of the pegmatitic phases of the diorite, where it has invariably been observed to be isotropic in thin sections. In its other occurrences it is more or less doubly refracting.

Epidote.—Epidote, a calcium-iron-aluminum silicate, occurs principally as a gangue mineral in the contact deposits, in places forming large crystal aggregates with garnet, quartz, and calcite. (See Pl. VIII, *D.*) These crystals are large and brilliant, being usually dark green with light-green reflections. Many of them are twinned, showing striated faces, and in certain instances are truncated at both ends with numerous faces. The most perfect of these crystals were found on the Green Monster Mountain on the east side of the Copper Mountain intrusive mass. Specimens of these epidote crystals were described as follows by Dr. Charles Palache,[1] of the Harvard Mineralogical Laboratory:

> The specimens at hand consist of several loose and a magnificent cluster of large crystals implanted on massive epidote. The only associated mineral is quartz in small clear crystals of later formation than the epidote.
>
> The epidote is very dark green to greenish black in color, but oil-green and translucent in thin crystals or where bruised or cracked. The larger crystals are in the form of nearly square tables, which measure as much as 5.5 centimeters each way and 3 centimeters in thickness. In the smaller crystals the tabular habit is less pronounced, and the mineral sometimes assumes the ordinary prismatic habit parallel to the *b* axis. The crystals are not infrequently doubly terminated. In the large group to which reference was made about 20 of the tabular crystals are found on a surface measuring about 15 by 20 centimeters, several of the crystals being over 3 centimeters on an edge, and attached by an edge in such fashion as to present an appearance altogether foreign to epidote. The crystals are frequently twinned according to the ordinary law for epidote, the twinning plane being the orthopinacoid.

To this Dr. Palache adds a list of crystallographic forms determined on the crystals and illustrates these by drawings. In conclusion he states that the Alaska epidote ranks among the finest occurrences of American crystallized minerals and is surpassed in the size, beauty, and complexity of its crystals only by the epidote from Knappenwand, in the Tyrol.

Quartz.—The mineral quartz (silicon dioxide), which is easily distinguished by its glassy appearance, is not so abundant in this district as in most mineralized regions. In the contact deposits it occurs only in small amounts and is generally well crystallized and associated with crystals of garnet and epidote. (See Pl. VIII, *D.*) Many of the crystals are doubly terminated and some are very large, the largest noted being 10 centimeters long. The quartz is usually superposed on the garnet and epidote crystals and also surrounds the ore minerals, thus indicating that it was the last mineral to form.

In the vein deposits it is associated with calcite, both minerals occurring with the ore or in veinlets that intersect the ore veins.

In the Jumbo mine a cleavable variety of quartz, containing numerous minute needles of hornblende, is associated with chalcedony.

Calcite.—Calcium carbonate (calcite), commonly known as carbonate of lime, is of widespread occurrence. It is readily recognized by its perfect cleavage and its softness. Calcite is particularly prominent in the contact deposits and also occurs in the vein deposits. Where it is associated with garnet and epidote it is usually of later formation and in many places fills the interstices between crystals of these minerals. (See Pl. IX, *A*, *B.*)

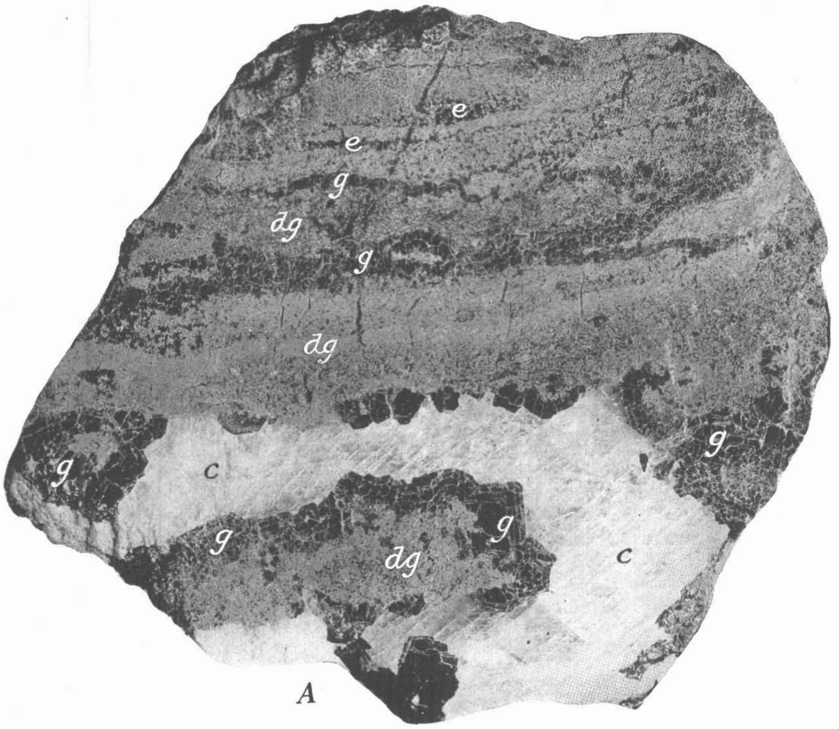
Diopside.—Diopside, a calcium-magnesium pyroxene, is a prominent gangue mineral of the contact deposits and is one of the principal constituents of the contact rock. In appearance it resembles epidote, for which it is often mistaken. Its color ranges from pale to deep green and it is generally scattered through the rock in minute crystals and grains, or it forms aggregates of needle-shaped crystals in veinlets and immediately at the borders of the contact rock. (See Pl. VII, *C.*)

[1] Am. Acad. Arts and Sci. Proc., vol. 37, No. 19, pp. 531-535, March, 1902.

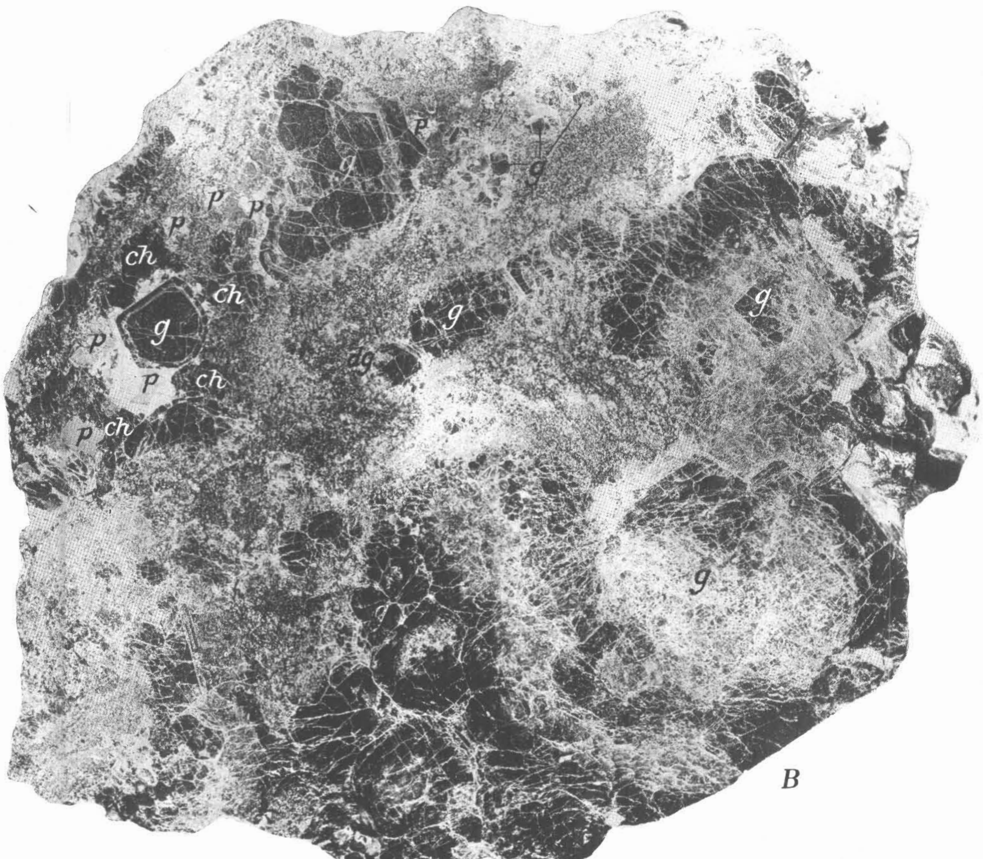
PLATE IX.

A. Massive contact rock from contact zone on Jumbo claim No. 4. In the groundmass of garnet-diopside and calcite are large, irregular crystals of garnet, which show marked zonal structure. This specimen contains some pyrite and pyrrhotite. *c*, Calcite; *e*, epidote; *g*, garnet; *dg*, calcite, diopside, garnet.

B. Contact rock showing vein structure. This rock is made up essentially of garnet, diopside, and some calcite and is traversed by veinlets bordered with garnet crystals and filled with calcite, which was introduced subsequent to the formation of the garnet. *g*, Garnet showing zonal structure; *p*, pyrite; *ch*, chalcopyrite; *dg*, calcite, diopside, garnet.



A



B

CONTACT ROCKS FROM COPPER MOUNTAIN AREA.

Scapolite.—Scapolite, a calcium-aluminum silicate containing sodium and chlorine, occurs in veins in the vicinity of the ore deposits in prismatic crystals 1 inch or 2 inches in length, with rough, uneven faces, and varies from white to gray in color. It also replaces feldspar in the diorite near certain contacts. It was found only in the vicinity of the Copper Mountain deposits and is not common. (See Pls. VII, *A*, and VIII, *B*.)

Amphibole.—The hornblende variety of amphibole, a calcium-magnesium-iron silicate, is a common but not abundant gangue mineral in some of the copper contact deposits. At the Jumbo No. 1 mine it forms clusters of crystals in the magnetite ore. It is also present in the older schists which have been altered by the contact rock. (See Tremolite, below.)

Wollastonite.—The metasilicate of calcium, wollastonite, forms radiating clusters of crystals in the garnet and diopside contact rock. It also occurs in finely radiating crystals in the limestone and quartzites and in the diorite a short distance from the intrusive contact. It belongs with the minerals of the contact deposits, but its occurrence away from the contacts suggests that the heat required for its formation was not so great as that required to produce the garnet and diopside, which occur at the contacts.

Orthoclase.—Orthoclase is intimately associated with diopside, garnet, and calcite (see Pl. X, *C*); it appears both in compact masses that show no cleavage and in cleavable grains. Its occurrence in grains, however, is rare. The variety adularia occurs in druses at the Jumbo mine in well-formed crystals nearly a centimeter long. Quartz and biotite crystals incrust much of the adularia. (See Pl. VIII, *F*.)

Biotite.—Biotite occurs as a later mineral in the veins with adularia at the Jumbo mine.

Dolomite.—Cavities in the contact rock have furnished a few small specimens of dolomite in rhombohedral crystals.

Spinel.—Small octahedral crystals of the dark-green spinel, pleonast, were observed accompanying the clear diopside in the Green Monster mine.

Serpentine.—Serpentine appears in two very different forms—(1) as irregular yellowish, slickensided masses in the dolomitic limestone, and (2) as small, globular, radial-fibrous aggregates evenly distributed through the limestone. The aggregates are almost microscopic in size and are nearly white. One specimen of limestone containing about 30 per cent of these spherules could not be distinguished in color from a pure limestone.

Tremolite.—Tremolite occurs as loose felty masses of slender white fibers in the limestone at the Green Monster claim. It was also noted at other localities, but only in small quantities.

Talc.—Talc was one of the last minerals to form in some of the veins and is found in druses of quartz; also along slipping planes in the ore bodies.

Zoisite.—Zoisite is usually associated with epidote, the two minerals in some places growing side by side apparently contemporaneously. Clusters of pink zoisite were also noted in veins of diopside.

Clinochlore.—Druses probably containing clinochlore, a soft greenish-blue micaceous mineral, were observed in the ore masses of the Jumbo No. 4 claim. This mineral is a hydrous silicate of magnesium and aluminum and is of secondary origin.

Zeolites.—Three varieties of zeolites were collected in the Copper Mountain area, namely, stilbite, chabazite, and heulandite, all hydrosilicates of aluminum with calcium and sodium. They were found in cavities formed in the tongue of contact rock just south of Summit Lake. They are secondary minerals occurring as druses with garnet and epidote crystals. The stilbite (see Pl. X, *A*) occurs in characteristic sheaf-like aggregates and the chabazite in nearly cubic rhombohedrons about a quarter of an inch in diameter. Heulandite was also noted in the form of flakes upon the stilbite crystals.

MINING IN THE COPPER MOUNTAIN AREA.

GENERAL CONDITIONS.

Copper is now (1908) being produced by only one large mine in the Copper Mountain area—the Jumbo mine, belonging to the Alaska Industrial Co. In past years the mines of the

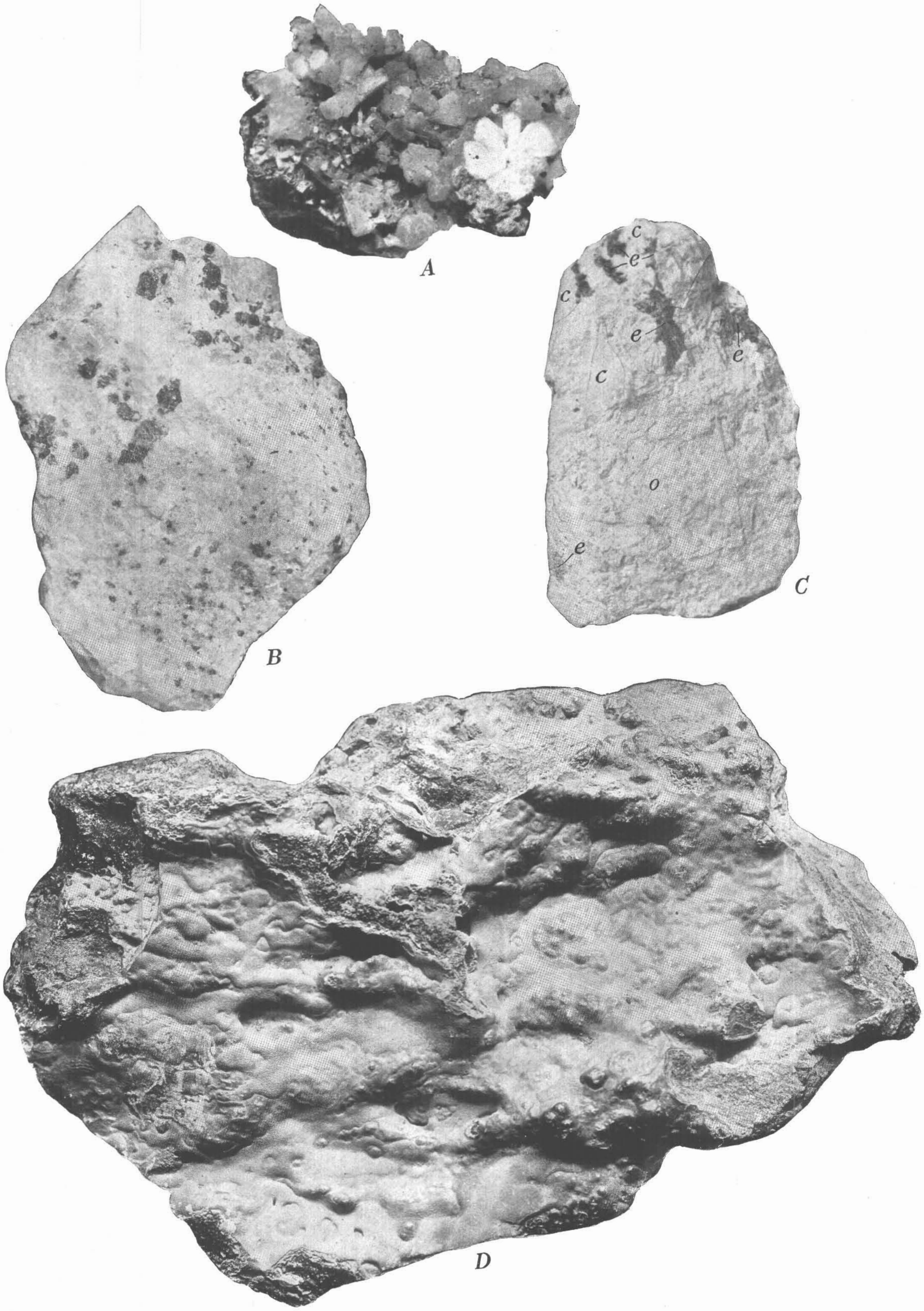
PLATE X.

A. Groups of crystals of stilbite, which occurs with chabasite in druses in the garnet-diopside-calcite contact rock. Specimen from tongue of contact rock south of Summit Lake.

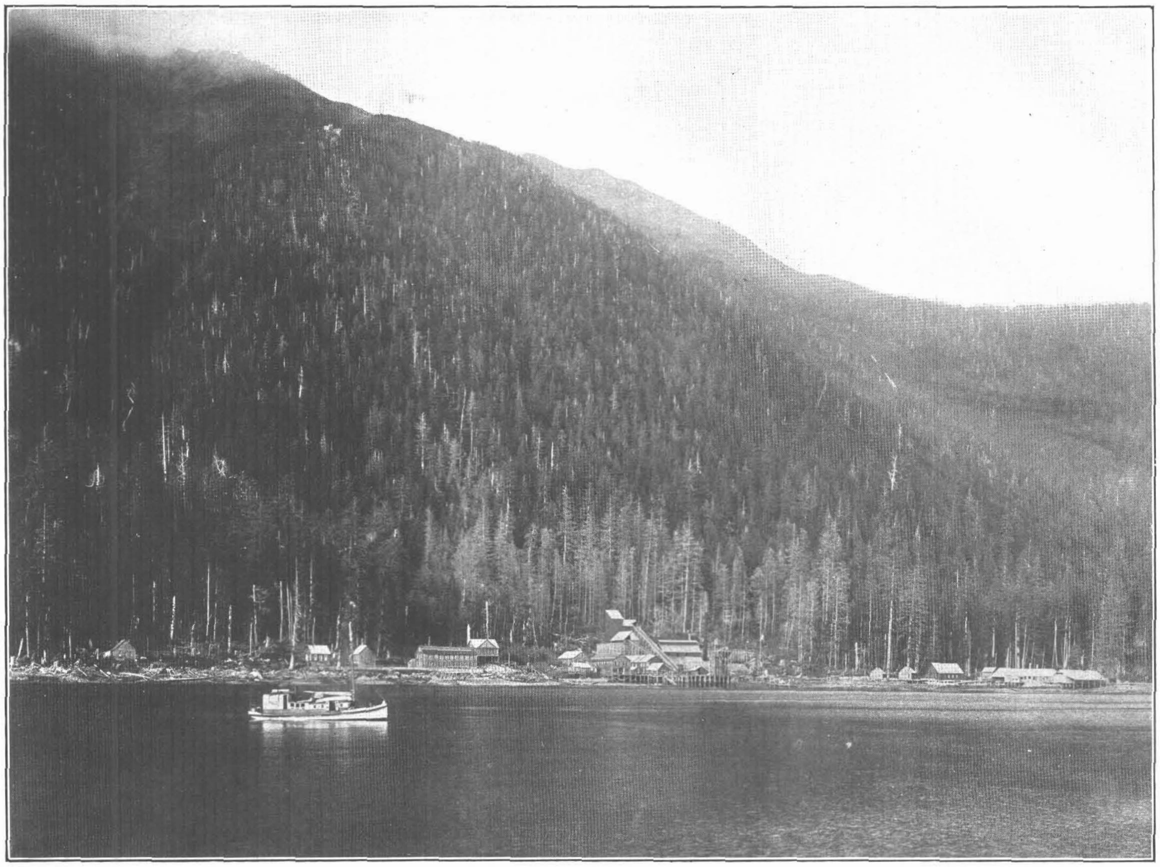
B. Specimen from pegmatite dike in granite on Jumbo claim No. 4, showing quartz and feldspar and small disseminated crystals of garnet.

C. Orthoclase with epidote and some calcite from veinlet in contact rock on New York claim, Copper Mountain group. *c*, Calcite; *e*, epidote; *o*, orthoclase.

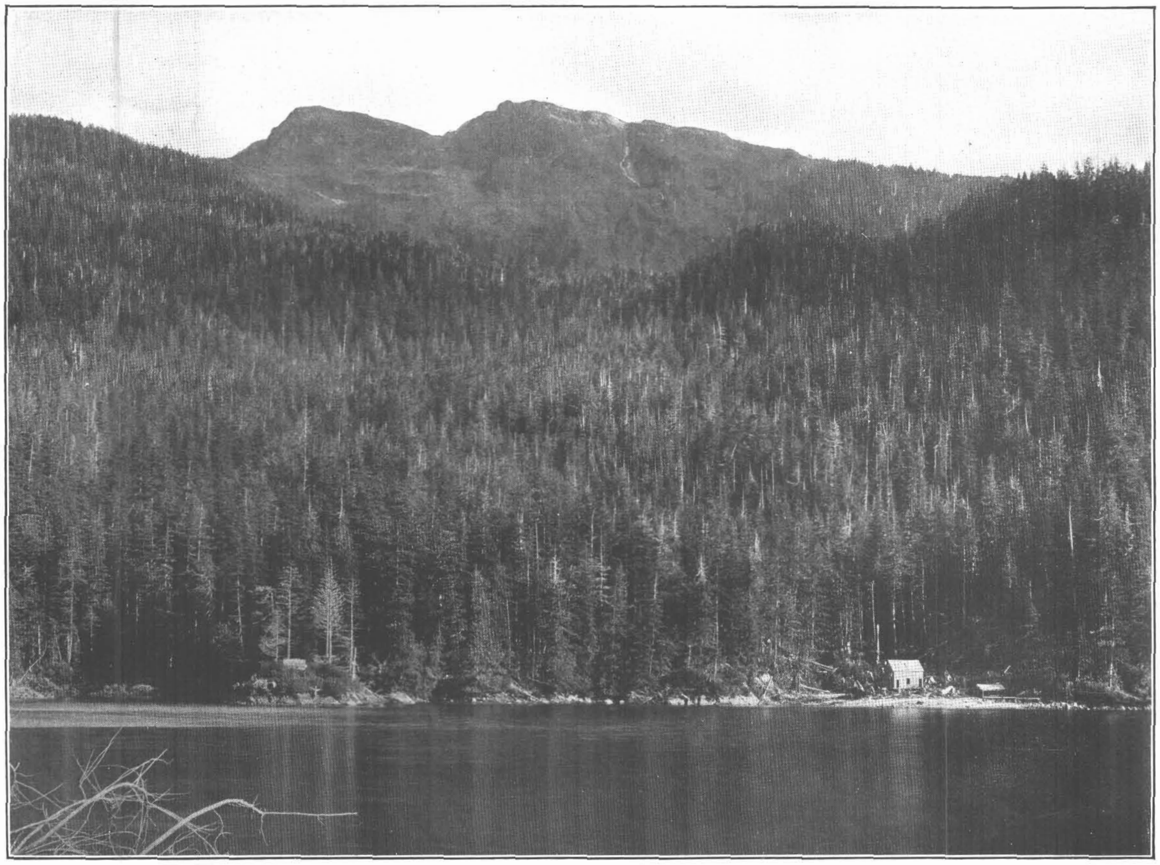
D. Malachite from surface workings on New York claim of Copper Mountain group. Underneath the coating of malachite there is some azurite and cuprite, with limonite.



MINERALS AND ORE FROM COPPER MOUNTAIN AREA.



A. SMELTER AND SAWMILL AT HEAD OF COPPER HARBOR.
An aerial tramway leads from the mine workings to the smelter. Photograph by Winter & Pond.



B. HETTA MOUNTAIN FROM HEAD OF COPPER HARBOR.
Photograph by Winter & Pond.

Alaska Copper Co. also have been productive, and small shipments of copper ore have been made from the Corbin and Copper City mines. Most of the ore shipped from these mines contains over 100 pounds of copper and a few dollars' worth of gold and silver per ton. The quantity of ore mined, however, is relatively small, and the underground workings, except those of the Jumbo mine, are not extensive. Mining presents no serious difficulties, as most of the deposits

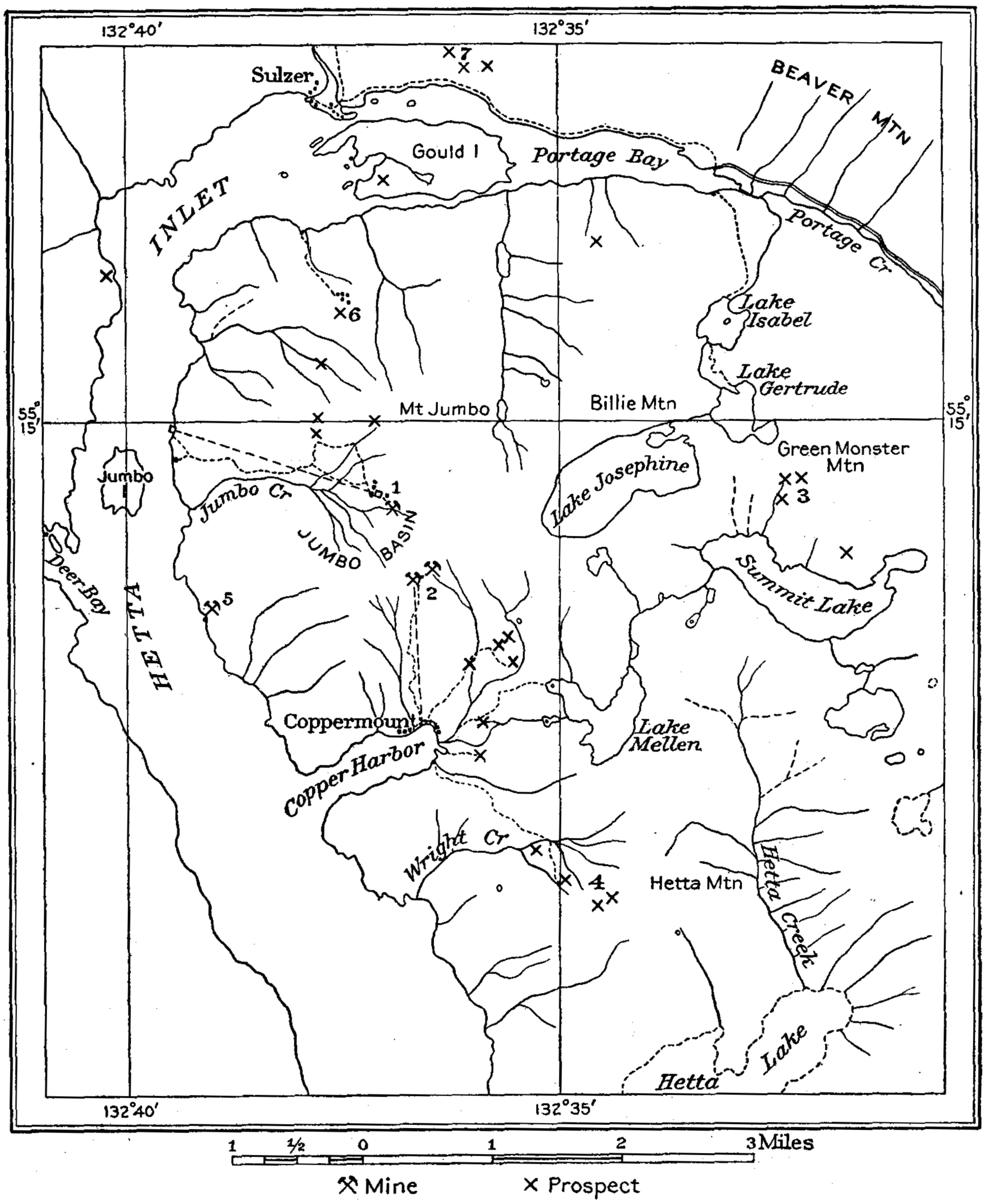


FIGURE 1.—Sketch map of the Copper Mountain area showing location of principal mines and prospects in 1908. 1, Jumbo mine, Alaska Industrial Co.; 2, Copper Mountain mines, Alaska Copper Co.; 3, Green Monster claims, Alaska Industrial Co.; 4, Hetta Mountain claims; 5, Corbin mine, Alaska Metals Mining Co.; 6, Houghton claims, Cuprite Copper Co.; 7, Sultana claims.

are located well up on the mountain sides, so that they can be developed by short tunnels, and the distance from the sea to most of the mines is only a few miles.

EARLY DISCOVERIES.

Mining development on Copper Mountain began in 1897, though the existence of copper ores in this region was known some years before by the natives who fished and hunted along the coast. The first mining claims were located on the ridge just west of Copper Mountain peak, where copper carbonate and other oxidized ores outcrop. These claims were staked and recorded by Charles Reynolds and Thomas Wright in the autumn of 1897. In the same year the deposits in the Jumbo Basin were discovered by Aaron Shellhouse, but they were not recorded until the following spring. In 1898 many other claims were located on Copper Mountain, and also on Green Monster Mountain, to the east, and on Hetta Mountain, to the south. The first man to interest capital in developing the Copper Mountain properties was Henry W. Mellan, through whose efforts the Alaska Copper Co. was formed, and development work was started in 1899.

The Jumbo Basin deposits, on the west slope of Copper Mountain, were visited in 1899 by William Sulzer, who recognized their value and formed the Alaska Industrial Co. to develop these deposits.

Many other claims were located in the vicinity of Copper Mountain between 1900 and 1903, including the Corbin, Houghton, Hetta Mountain, and the Sultana group.

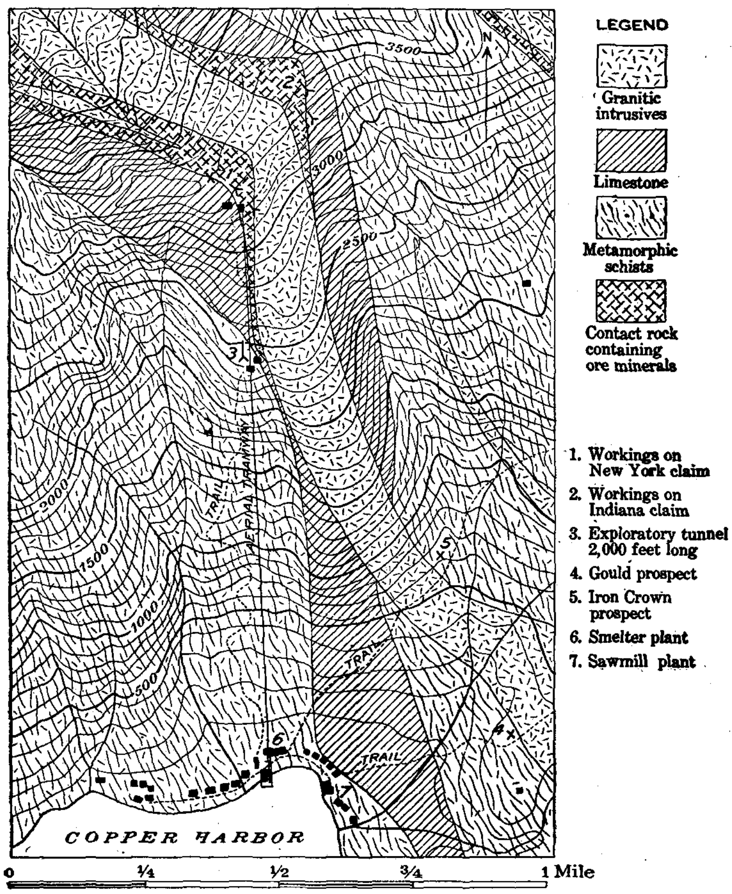


FIGURE 2.—Sketch map showing geology and mine workings on property of Alaska Copper Co. and adjacent mining claims in 1908.

THE MINES.

ALASKA COPPER CO.

Location of property.—The group of claims belonging to the Alaska Copper Co. occupies the south slope of Copper Mountain, extending from tidewater at Copper Harbor to the crest of the ridge at an elevation of 3,500 feet. (See fig. 2.) There are 18 claims in the original group, though developments have been advanced mainly on the New York and Indiana claims, which are on the top of the ridge.

Development.—The first developments were made by means of open pits on the outcrops of the ore deposits along the ridge, at altitudes of 3,300 and 3,400 feet. The lower of these outcrops is now (1908) on the New York claim, and tunnels 200 and 700 feet in length have been driven at levels 150 and 300 feet below the open pit to explore the deposit. These tunnels are connected by raises. Some stoping done in the tunnels showed that the ore was irregular in its occurrence and that it consisted of rich pockets of copper carbonate. In the low tunnel the carbonate ore is replaced by sulphides, which are more disseminated in the garnet gangue rock, though the rock contains also carbonate ores. This deposit has been explored at still greater depth by a tunnel 3,000 feet long, this measurement including crosscuts. This tunnel is run at an elevation of 2,350 feet and undercuts the surface outcrops of the ore deposit at a depth of nearly 1,000 feet. It follows the contact zone of the diorite, first with quartzite and next with limestone, and the tunnel itself zigzags from one contact to the other, usually keeping within the contact rock. Its general course is northeasterly to a point 1,400 feet from its mouth, where it branches, the left or northwestern branch continuing for several hundred feet along the contact to a point almost directly under the surface outcrop on the New York claim and the northeastern branch penetrating the massive granite belt for 700 feet toward the Indiana lode. (See fig. 3.)

The principal developments on the Indiana claim are at a point 800 feet northeast of the open pit on the New York claim and at an elevation of 3,500 feet. Here a large open pit has been made and tunnels have been driven at different points, from 40 to 220 feet below the level of the pit, to investigate the deposit in depth. These openings are all in the contact rock and include about 600 feet of exploratory tunnels, crosscuts, and raises, but only small masses of minable ore have been found in them. An eastward extension of the tunnel at the 2,500-foot level would probably traverse the same contact rock at a depth of 1,150 feet below the surface. From the Indiana workings a surface tram, 1,400 feet long, extends around the mountain to the New York claim, from which an aerial tram extends to Copper Harbor. Pits, trenches, and short tunnels, most of them in the contact rock, have disclosed some ore on other claims belonging to this group, but no large masses have been found on these claims and the work done on them has been small. The total mine development up to the time the mine closed in 1907 consisted of about 4,200 feet of tunnels and 500 feet of shafts and raises, besides many open pits. The ore mined has been taken principally from the upper workings on the New York claim.

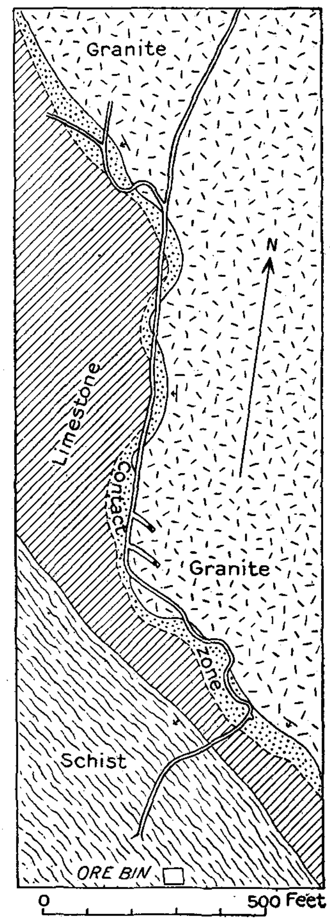


FIGURE 3.—Plan of long tunnel of Copper Mountain mine, showing rocks near contact zone.

Smelter.—The smelting plant stands close to tidewater at the head of Copper Harbor. It consists of a 250-ton Allis-Chalmers blast furnace, ore bins of 2,500 tons capacity, coke bins of 1,200 tons capacity, and a sampling mill, besides the usual appliances for granulating and removing slag. (See Pl. XI, *A*.) The ore from the mine workings is delivered to the sampling mill bin by an aerial tramway 6,000 feet long, and the ore shipped to the smelter is unloaded on the wharf into receiving bunkers of 1,000 tons capacity, from which it is drawn off into cars and hoisted on an inclined tramway to the sampling mill.

In addition to the smelting plant there is a sawmill, machine shop, store and warehouse, assay office, and compressor plant. The power required for the smelter and compressor plant was derived from Reynolds Creek, the water being transmitted 1,000 feet by a 22-inch pipe line to two 300-horsepower Pelton wheels.

The smelter was first blown in for a run in June, 1905, and was operated for short periods during 1906 and 1907. The mines above the smelter did not furnish enough ore for the furnace and for fluxing and it became necessary to go to other mines for ore. The Rush & Brown mine, on the east coast of the island, was therefore leased by the Alaska Copper Co., and small lots of ore were purchased from other mines on Prince of Wales Island. The smelter was run at intervals on these ores until early in 1907, when it was shut down, and no attempt has yet been made (1912) to operate it again.

Ore deposits.—The two principal ore deposits that have been developed on the New York and Indiana claims are contact deposits separated from one another by a belt of diorite 800 feet wide. Along both sides of this belt of intrusive rock lie zones of contact rock, composed essentially of garnet-diopside and epidote, and in these zones the ore is found either scattered or in concentrated masses. At the surface workings on the New York claim a mass of rich ore occurs in the contact rock between the diorite and limestone, the limestone forming the hanging wall. (See Pl. VI, *B*, p. 32.) Most of the copper ore, which was originally chalcopyrite, has been altered to copper carbonates and limonite, and these secondary ores have spread out into the somewhat fractured limestone hanging wall. This spreading, which is attributed to the action of meteoric waters, in few places extends more than 50 feet into the hanging wall. On the surface this ore mass appeared to be extensive, but in the tunnels below the surface pit it was rather small, and in the long tunnel that follows the contact for 2,000 feet only scattered chalcopyrite was found and no minable ore. (See fig. 3.) In the upper tunnels the secondary ores were less prominent than in the surface pit and in the long tunnel they were entirely absent. The contact rock exposed along the surface and in the long tunnel ranged in width from a few feet to 50 feet. In two places veins of this contact rock that occupied fissures in the diorite had been followed for short distances by crosscuts from the main tunnels. The contact rock contained inclusions of both the limestone and the quartzite. Faulting and slipping planes were observed within the contact rock, but the displacements along these were slight.

The contact deposit on the Indiana claim is on the eastern contact of the diorite belt. Quartzite and amphibolite cut by numerous quartz stringers form the hanging wall, though the contact rock includes masses of limestone. The garnet and epidote minerals of the contact rock have penetrated and altered these quartzites for a few hundred feet away from the contact. The ore exposed in the open pit and tunnels is similar to that on the New York claim, though it is less concentrated, and the valuable metals it contains are more scattered. The ore mined from this deposit contained only a little copper and from $1 to $2 in gold and silver. At both the New York and Indiana contact deposits there is a gradual change or blending of the contact rock and ore into the diorite, due to replacement of the minerals composing the diorite by those composing the contact rock. This zone of partial replacement is generally from 2 to 5 feet wide. The contact action is fully discussed under a separate heading (p. 102).

ALASKA INDUSTRIAL CO.

Location of properties.—The present (1908) holdings of the Alaska Industrial Co. in the Copper Mountain area include the Jumbo group (29 claims) and the Green Monster group (14 claims) located on Green Monster Mountain. (See Pl. IV, *A*, p. 29.) The mining developments here described include only those made up to 1908. Since then some other notable advances have been made.

JUMBO GROUP.

The claims of the Jumbo Group occupy the slopes of Jumbo basin, on the northwest side of Copper Mountain. These claims extend from a point 500 feet in elevation and a mile from tidewater nearly to the mountain summit, which stands at an elevation of 3,946 feet. The main deposits being explored lie at elevations between 1,500 and 1,900 feet, on the east slope of Jumbo Basin, on Jumbo claims Nos. 1, 1A, and 2, and between elevations of 1,500 and 2,000 feet on Jumbo claims Nos. 4 and 14. Practically all the ore mined and shipped has been taken from the deposits on Jumbo claim No. 4.

Development.—The deposits included in the Jumbo group were first exploited in 1902, and during succeeding years numerous prospect tunnels were driven and test pits sunk on the different claims. After a promising ore body had been opened on claims Nos. 4 and 14, located at elevations of 1,700 and 2,050 feet above sea level, it was necessary to devise a means of transporting the ore to tidewater. For this purpose a Riblett aerial tram 8,250 feet long and an additional tram 600 feet long were erected in 1905–6, thus connecting the beach with the lower tunnel of the mine workings, 1,700 feet above sea level. At the beach a wharf with a frontage of 150 feet was built and ore bins of 4,000 tons capacity were erected. While this work was in progress the development of the ore deposits was advanced, and early in 1907 shipments of the ore to the Tyee smelter, in British Columbia, were begun. In 1908 the mine workings on Jumbo claim No. 4 consisted of four tunnels at elevations between 1,570 and 1,950 feet, and an open cut at an elevation of 2,050 feet. (See fig. 4.) The main working tunnel, or tunnel No. 3, is at an elevation of 1,700 feet. At a point 180 feet from its mouth a 130-foot vertical raise connects this tunnel with the stopes in the ore body and with tunnel No. 2. At a point 40 feet above tunnel No. 3 a stope has been extended to the west and 30 feet above this an exploratory drift has been run eastward into the ore. The floor of the main stope is 100 feet above the level of tunnel No. 3. This stope is 240 feet long, 10 to 40 feet wide, and extends for 30 feet above the level of tunnel No. 2. A second sulphide body, separated

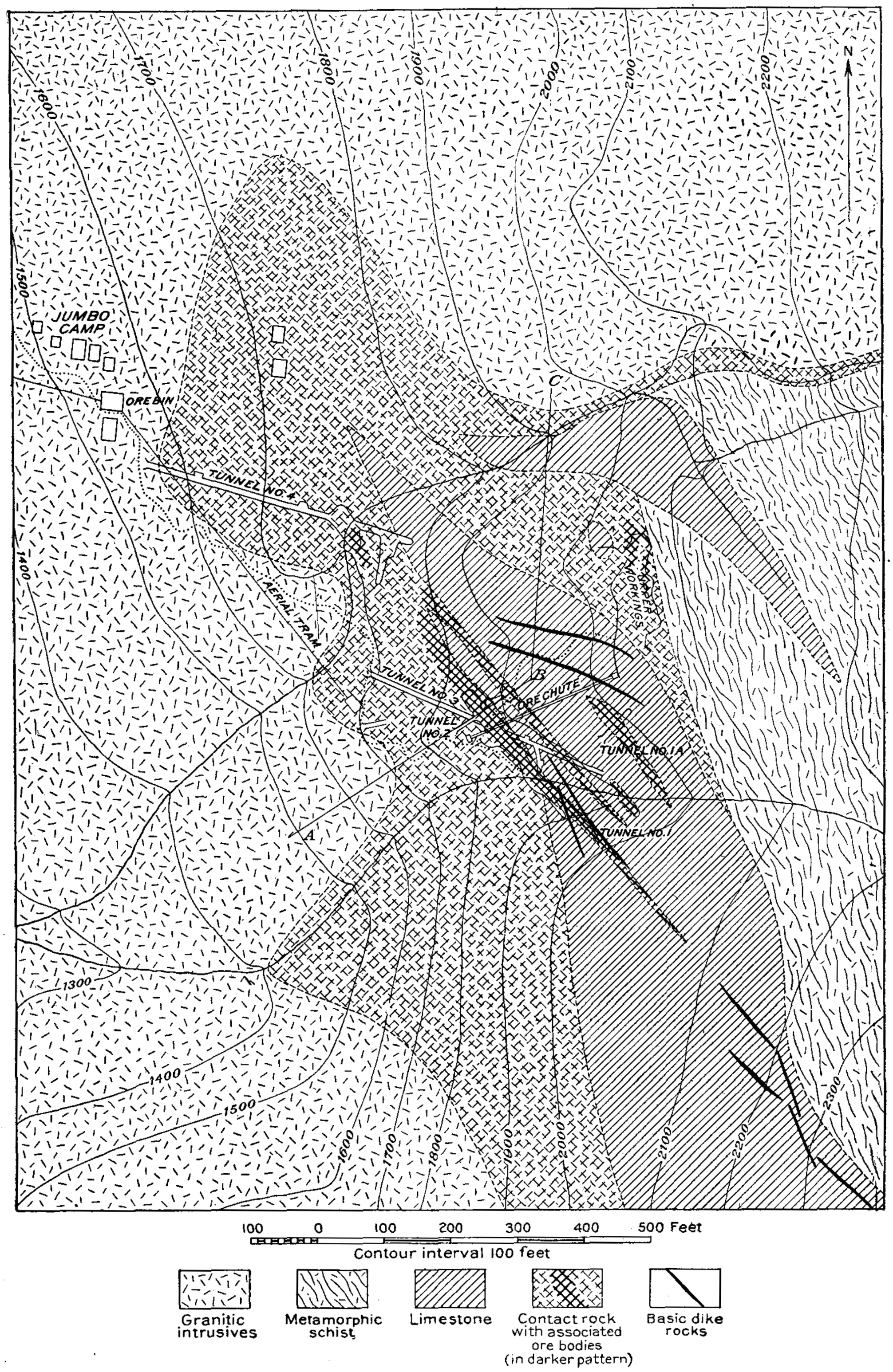


FIGURE 4.—Geologic sketch map showing surface geology and mine developments (1908) on Jumbo claim No. 4. *A B C*, line of cross section, figure 5.

from the main deposit by 40 feet of contact rock, has been opened on level No. 2, northeast of the main deposit, and has yielded a large quantity of ore. The ore from these two ore bodies goes through the raise to tunnel No. 3, where it is trammed to the upper terminal of the aerial tramway, from which it is carried to the ore bunkers at the shore.

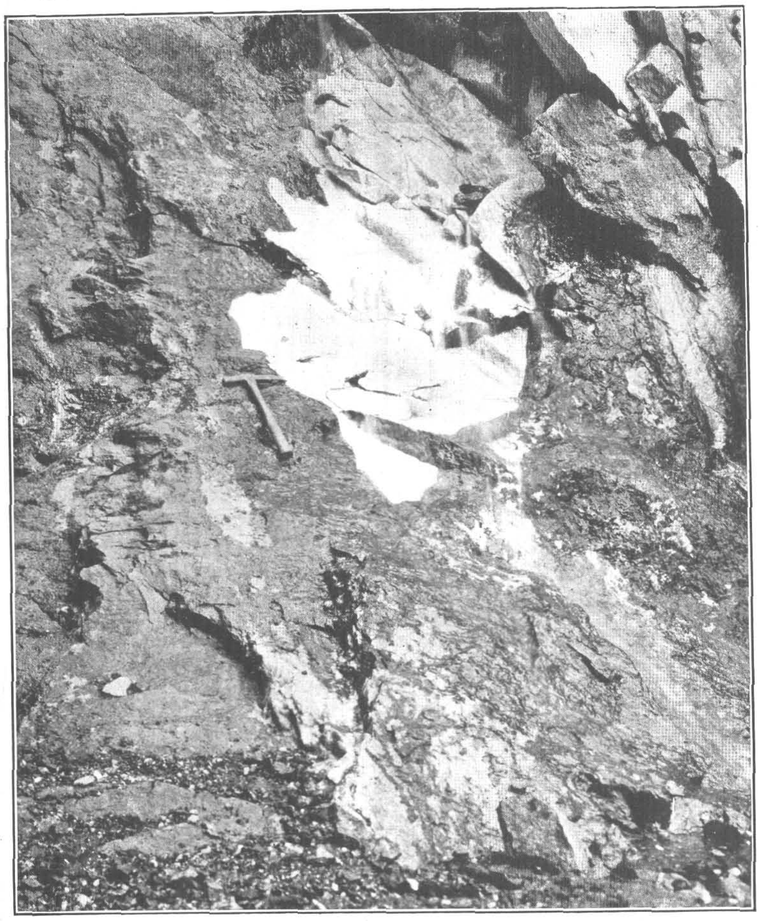
The southeastern extension of these deposits is being explored by tunnels in Canyon Creek. In tunnel No. 4, which is at an elevation of 1,570 feet, just above the upper terminal of the tramway, two small ore bodies were crosscut and yielded a small quantity of ore. These bodies may represent the northwestern extension of the two ore deposits opened in tunnel No. 2. This level is being advanced to undercut the raise in tunnel No. 3 and will eventually serve as a passageway for all the ore mined from the workings above, thus eliminating the necessity of the auxiliary tramway from tunnel No. 3.

The uppermost workings consist of an open cut across a width of 200 feet at an elevation of 2,050 feet, on Jumbo claim No. 14. In this cut the irregularity and sporadic occurrence of the ore is well shown. At one point a face of massive sulphide ore 6 feet across is surrounded by barren gangue rock; at other points sulphides were finely disseminated in the rock in sufficient amounts to make a minable ore.

The developments on Jumbo claim No. 1 have been extensive and have exposed a large body of low-grade ore. The uppermost workings are at an elevation of 1,890 feet and consist of an open cut exposing considerable copper carbonate and limonite ore in the contact rock. This carbonate, however, does not extend to a great depth. Just below this cut the deposit is exposed in a steep bluff 100 feet high and 100 feet wide, along the foot of which the ore consists of masses of sulphides accompanied by magnetite. Below and west of this point, at an elevation of 1,660 feet, a tunnel crosscuts the limestone hanging wall and enters the contact rock, which at that point was barren. Another larger bluff of ore is exposed east of this tunnel, at an elevation of 1,580 feet, on Jumbo No. 2 claim. This deposit, known as the magnetite body, has been undercut by two tunnels, one at 1,540 and the other at 1,480 feet. The upper tunnel starts in the magnetite deposit, penetrates it for 50 feet, and enters the diorite footwall for 6 feet. The contact between the ore body and the footwall showed a gradation from the contact rock and the intrusive rock, though the gradation was rather abrupt. Near the contact the ore is of fine texture, is rich in diopside and magnetite, and contains disseminated sulphides, whereas at the entrance to the tunnel the gangue is essentially garnet and calcite, with small masses of chalcopyrite. The lower tunnel crosscuts the limestone hanging wall for 55 feet and penetrates the ore body for 10 feet. The contact between the ore body and limestone is sharply defined. The downward extension of this ore body is exposed on Jumbo claim No. 1A by two tunnels, one above the other, at elevations of 750 and 840 feet. The upper tunnel crosscuts a hanging wall of schist that is largely replaced by the contact rock and enters the sulphide ore 25 feet from its mouth. In the lower tunnel, which is 240 feet long, the hanging wall consists of a banded quartzite or silicified schist, which grades into banded contact rock containing disseminated sulphides and magnetite. The inner end of the tunnel extends into the diorite footwall. The contact deposit exposed in this tunnel is 100 feet wide, but the ore in it is scattered and is of lower grade than the ore exposed in the upper tunnels. Explorations on Jumbo claim No. 3, which lies between the workings on Jumbo claims Nos. 2 and 4, have exposed other deposits of chalcopyrite and magnetite, on which developments are being advanced. Disseminated deposits of sulphides in the schists have been explored by tunnels and open cuts on Jumbo claims, but the metallic content of the ore exposed was low.

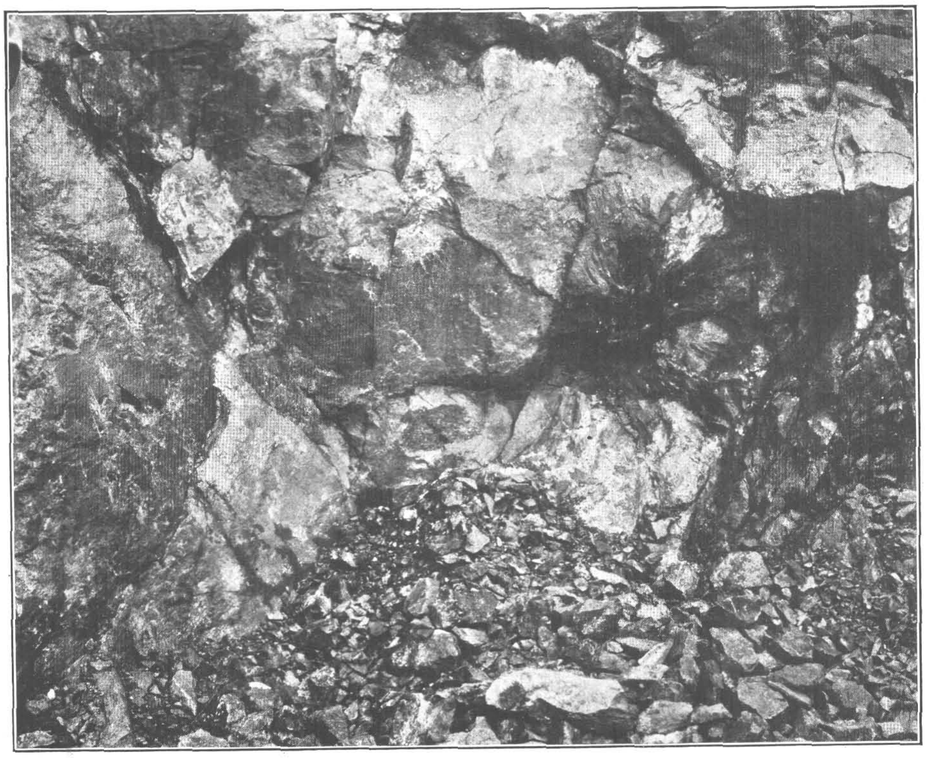
Ore deposits.—The general relations of the rocks of this area, which are similar to those in the Copper Mountain group, already described, are presented on the geologic map (Pl. I, p. 16) and in the sketches of the mine workings (figs. 4 and 5). The main diorite mass forms the footwall of the deposits, the hanging wall being in some places a crystalline limestone and in others a silicified schist or banded quartzite much metamorphosed and varying in color from gray to greenish and reddish.

The copper deposits being mined on Jumbo claim No. 4 consist of irregular bodies of chalcopyrite-pyrrhotite ore, 10 to 40 feet wide and 100 to 200 feet long, One mass has been opened for a depth of 150 feet, but the extent of the others is not known. The contact zone



A. MASS OF LIMESTONE INCLOSED IN CONTACT ROCK.

Point of hammer rests on reaction rim composed essentially of amphibole. (See Pl. VIII, *C.*) View taken just below tunnel No. 1, Jumbo claim No. 4.



B. MASS OF CHALCOPYRITE ORE INCLOSED IN CONTACT ROCK.

Dark patch on right is massive chalcopyrite. View taken just above mouth of tunnel No. 2, Jumbo claim No. 4.

within which these masses occur (see figs. 4 and 5) lies between the granitic intrusive and a belt of limestone, above which metamorphic schists appear. This mineralized zone is nearly surrounded by the granitic contact and in this respect differs from the other contact deposits.

No definite line of separation between the contact rock and the granitic intrusive can be drawn, as the mineral solutions appear to have replaced the mineral components of the rock adjacent to the contact. The beds of limestone on the hanging-wall side of the contact zone are fractured and faulted and masses of limestone are completely inclosed in the contact rock. (See Pl. XII, *A*.) On the other hand, masses of the contact rock are surrounded by the limestone, suggesting the replacement of the limestone by ore-bearing minerals. The contact rock is composed mainly of garnet, diopside, epidote, and some calcite, and these minerals are in places so closely associated as to resemble a compact felsitic rock, so that the rock might be mistaken for felsite. Near the ore masses the contact rock is generally coarsely crystallized, the garnet, epidote, and diopside forming aggregates of well-developed crystals and the calcite filling the interstices between the crystals. In the ore bodies the chalcopyrite occurs in small masses or is scattered through the inclosing contact rock and is associated with pyrrhotite and pyrite. Except the local change in the character of the crystallization of the contact rock there are no indications within the contact zone that may be used as a guide in the search for these ore masses.

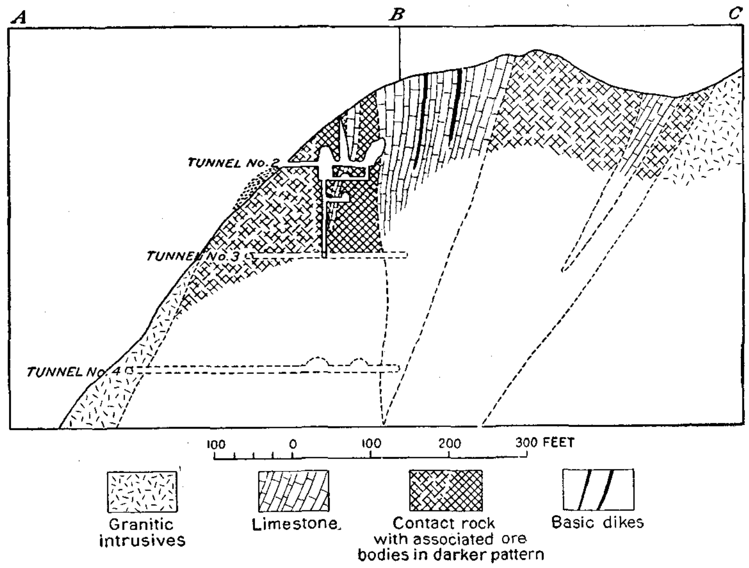


FIGURE 5.—Cross section along line *ABC* on figure 4, showing geology and mine developments (1908) on Jumbo claim No. 4.

The ore bodies on Jumbo claims Nos. 1 and 2, though similar in most respects to those on Jumbo claim No. 4, contain less copper and more magnetite, a mineral that was notably absent from the deposit on the Jumbo No. 4. The ore bodies have been well exposed by erosion over broad areas and in places are in the form of a sheet a few feet wide overlying the diorite footwalls. (See fig. 6.) These outcrops occur between the 1,500 and 2,000 foot contours, above which the diorite alone was observed. The width of the contact rock between the hanging wall and footwall varies from 10 to 100 feet, though in places the diorite and limestone lie in direct contact. The ore bodies within this contact zone are from 5 to 50 feet in width and a few hundred feet in length. They have not been developed to any considerable depth. The ore masses are confined to the diorite footwall and are sporadic in their occurrence, though they are connected with one another by more or less barren gangue or contact rock. The average ore from this deposit contains a high percentage of iron and nearly sufficient silica for smelting. (See fig. 6.) The ore carries not only copper but gold and silver.

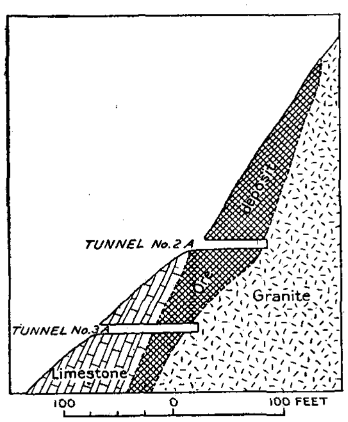


FIGURE 6.—Cross section of magnetite deposits on Jumbo claim No. 2 (1908).

GREEN MONSTER GROUP.

Situation.—The Green Monster group of claims occupies the northern and western slopes of Green Monster Mountain, 2½ miles east of Copper Mountain and 3 miles from the tide flats at the head of Portage Bay, from which a route, partly by trail and partly by boat, crossing two lakes each half a mile wide, at altitudes of 600 and 1,680 feet, respectively, leads to the principal mine workings, at an elevation of 2,800 feet. Another approach to these claims, also partly by trail and partly by boat, is from Copper Harbor, as indicated on the map (Pl. II, p. 28) and on figure 1.

Development.—Although these claims were located in 1900, developments up to 1908 have been meager, and no attempt has been made to advance the exploration beyond the required assessment work. Two tunnels have been driven, each 65 feet long, one on Green Monster claim No. 1 and the other on Diamond B. claim. On the Iola claim a pit 8 feet deep has been sunk and trenches have been dug along the ore body.

Ore bodies.—Ore bodies at the contact of the limestone and diorite are found on the Iola, Black Warrior, and Diamond B. claims. The deposit on the Iola claim has been opened by a small pit and by surface stripping and consists of a mass of magnetite-chalcopyrite ore, 10 feet wide, inclosed in the garnet-epidote gangue, which at this point occupies a width of about 25 feet between the limestone hanging wall and the diorite footwall. Along this contact other smaller ore masses were observed on the Iola and Black Warrior No. 2 claims, but they were apparently of little consequence. On the Black Warrior claims Nos. 1 and 5 similar ore deposits lie adjacent to the contact of the diorite and limestone and in a black slate band that extends along the mountain crest, striking N. 30° W., but these deposits have not been prospected. On the Diamond B. claim a tunnel 65 feet long has been driven along the contact of the limestone with a porphyritic dike 50 feet or more in width, striking N. 30° E. The main contact of the diorite lies about 150 feet to the west. The face of the tunnel is in limestone and in the tunnel the garnet-epidote vein rock is exposed across a width of about 10 feet and for a length of 50 feet. Small masses of copper sulphide occur in this contact rock, but the metal content of the vein as a whole is low.

A vein deposit filling an irregular fissure in the limestone occurs on Green Monster claim No. 1. This vein appears to be an offshoot from the main contact zone just west of it. The vein is undercut by a tunnel 65 feet long and is exposed by trenches for 250 feet along the surface. The vein strikes S. 20° E., dips vertical, and averages 6 feet in width. The copper occurs in small masses and disseminated particles throughout the garnet-epidote-calcite gangue. Associated with the chalcopyrite ore is pyrite, and in places along the surface limonite, malachite, and azurite occur.

A third type of mineralization is exposed on Black Warrior claim No. 2, where a narrow vein containing galena, pyrite, and chalcopyrite has been deposited along the contact of a porphyry dike and the limestone country rock at a point about 1,000 feet from the granite contact. This ore, though of good quality, has not been found in large quantity.

In general the ore bodies on the Green Monster group are similar to those on the Jumbo group, but do not appear to be as great in size and extent. The position of the property necessitates the building of a tramway for 3 miles in order to ship the ore, and conditions of mining are less favorable here than at many other points along the coast.

CUPRITE COPPER CO.

Situation and development.—The property of the Cuprite Copper Co., known as the Houghton group of claims, is on the northwest slope of Mount Jumbo, between elevations 1,000 and 2,000 feet, and is 1 mile from Hetta Inlet. (See fig. 1.) They include the diorite contact zone exposed on the Jumbo group to the south, and the ore bodies under exploration are of the same general type. The claims, including a mill site at tidewater, were located in 1901, and from that time to the end of 1905 the developments were meager, assessment work alone being done. Early in 1906 the properties were acquired by the Cuprite Copper Co., two more claims were located, and active development was begun and was continued during 1907 and 1908. The present mining camp is at an elevation of 1,500 feet and the mine workings between 1,600 and 1,700 feet. A tunnel at an elevation of 1,600 feet, 100 feet long, and another at 1,700 feet, 80 feet long, had been driven in 1908 to explore the ore body along the contact, its surface exposure being 100 feet above. At other points on these claims short exploratory tunnels and cuts have been made.

Ore body.—The copper deposits on which explorations are being made is included in the garnet-epidote contact rock, which occupies a zone 25 to 75 feet wide between the diorite and limestone. This zone strikes N. 45° E. and dips steeply to the northwest. The ore body is developed on the surface by a 30-foot cut and a 15-foot pit, in which a body of massive chalcopyrite ore 5 feet wide is exposed. In the tunnels that enter the contact zone small amounts of copper ore have been found but no large ore body. The chalcopyrite is associated with magnetite, pyrite, and some pyrrhotite. These claims showed less general contact metamorphism and less ore than the Jumbo group.

SULTANA GROUP.

Situation and development.—The Sultana group, consisting of six claims, is on the north side of Hetta Inlet, about a mile east of Sultana, and extends from tidewater to an elevation of 1,000 feet on the south slope of Beaver Mountain. The principal developments have been made on the Sultana claim, though prospecting has been advanced on the adjoining claims, the Index and Vulcan. The total work done each year up to 1908, however, amounts to little more than the assessment work.

Ore bodies.—The ore bodies exposed are contact-metamorphic deposits underlain by a granitic intrusive, banded siliceous limestone forming the hanging wall. A gangue of garnet and epidote, with considerable calcite, has been deposited along the contact, in which sulphides of copper and iron are sparingly distributed in small masses and disseminated particles.

At a point on the Sultana claim at an elevation of about one-third of a mile from the shore a tunnel 130 feet long was driven in the granodiorite footwall without discovering ore. Another tunnel 430 feet in elevation exposes at its entrance a mass of chalcopyrite ore 3 feet wide and then crosscuts the garnet-epidote gangue rock for 25 feet, showing practically no ore. On the Index claim, which is east of the Sultana claim, at an elevation of 600 feet, an open cut 60 feet long exposes small amounts of chalcopyrite, not sufficient to make a profitable ore, associated with magnetite and pyrrhotite in banded garnet-epidote rock. On the Vulcan claim, north of the Sultana claim, at an altitude of 520 feet, is an open cut 60 feet wide. Here garnet-epidote rock occurs with large included fragments of banded limestone containing pyrrhotite and chalcopyrite in masses a few feet wide. A relatively small amount of ore is developed on these properties. The ore at this prospect was reported to carry cobalt in considerable amount, but a sample taken by the writer and submitted for analysis gave only a trace of cobalt and less than 0.2 per cent of nickel.

ALASKA METALS MINING CO.

Situation and development.—The property of the Alaska Metals Mining Co., formerly the Corbin mine, is close to tidewater on the east side of Hetta Inlet, $1\frac{1}{2}$ miles north of the entrance to Copper Harbor. This property, which includes four claims, was located in February, 1905, and the following summer ore was shipped to the smelter at Coppermount. Early in 1906 the mine was sold to the Alaska Metals Mining Co., which began active development and equipped the property with an air compressor, a hoist, and a steam-power plant and erected a small wharf and several buildings. The position of the ore body necessitated the sinking of a shaft 100 feet, and at this depth considerable crosscutting and drifting were extended to explore the ore body at this level. A tunnel, started near the shaft, has been driven along the vein for 210 feet, but the results were not encouraging. Operations on this property were suspended during the winter of 1907 and were not renewed in 1908.

Ore bodies.—The ore body is a vein deposit of nearly massive sulphide ore inclosed in a narrow fissure parallel to the stratification of the greenstone schist country rock. The vein is from 1 foot to 3 feet wide and has been exposed for about 250 feet, for which distance it strikes N. 70° W. and dips 70° SW. A tunnel 210 feet long was driven southeastward along the vein and in this tunnel the vein narrows to a thin gouge seam and widens again at several points, its continuation being indicated by the bleached appearance of the country rock. The footwall of the vein is a dark-green schist and appears less altered than the hanging wall, which is a pale-green talcose schist. Grooves caused by slipping were observed on both the footwall and the hanging wall. These grooves pitch 50° NW., and the ore shoots most likely follow this direction. In the vein itself occasional slickensides were observed, indicating movement since the deposition of the ore. The vein is cut by dikes of diabase, 2 to 4 feet wide, striking N. 10° E. and dipping 70° NW., nearly at right angles to the prevailing rock structure. The ore is principally pyrite, containing chalcopyrite associated with some quartz and calcite as gangue minerals. Besides the small quantity of copper, the ore carries, as reported, gold and silver amounting to about $3 per ton. Explorations at other points on these claims may reveal similar vein deposits.

COPPER CITY MINE.

Situation and development.—The Copper City mine, also known as the Red Wing group, consisting of four claims, is near tidewater on the east side of Hetta Inlet, 7 miles south of Copper Harbor. This property has been a copper producer in a small way ever since operations first began, in 1903, the ore being sacked and shipped to the Tacoma smelter. The developments up to 1908 have been confined to the Red Wing claim, where the vein deposit has been opened by an inclined shaft 120 feet in depth. From this shaft two levels, 50 and 100 feet, respectively, below the surface have been driven. The 100-foot drift is the working level and this has been carried along the vein for 200 feet north and 50 feet south of the shaft. At a point on the level 75 feet north of the shaft a 60-foot winze has been sunk and from this a drift 50 feet long has been run. Most of the ore above the 100-foot level has been mined, and it is proposed to sink the shaft an additional 100 feet and open up a 200-foot level.

Ore body.—The ore body, a vein deposit of nearly massive sulphide ore, is inclosed in a slate-greenstone country rock parallel to the bedding and corresponds in general character to the ore body at the Corbin mine already described. The country rock grades from a black slate or siliceous schist to an amphibole schist or altered greenstone, the general strike being N. 20° E. and the dip 60° NW. These schists and also the vein deposits are crosscut by several diabase dikes, 1 foot to 5 feet wide, which strike about N. 30° W. These dikes were intruded after the main ore deposition, but subsequent mineralization has deposited small amounts of mineral in veinlets in them, and the ore bodies, where crosscut, usually continue along the same line of strike on opposite sides of these intrusives. The vein as exposed in the shaft varies from 6 inches to 4 feet in width, narrowing to a gouge seam at a depth of 100 feet. At this level the vein appeared to be displaced for a short distance toward the footwall side, where it was again found, and on it a 60-foot winze was sunk, in which the vein was reported to be wider. Similar but smaller veins, trending parallel to the main vein, have been exposed by surface cuts and trenches at other points on the property, but none of these have been developed.

The ore is composed essentially of chalcopyrite, pyrite, sphalerite, and rarely hematite (specularite), associated with quartz, calcite, and epidote as gangue minerals. Surface oxidation has altered the chalcopyrite in places to limonite and cuprite, and along joint cracks in the country rock malachite and small films of native copper were observed. In addition to copper each ton of the ore contains gold amounting to $3 to $6 and silver amounting to $1 to $3, as well as 6 to 9 per cent of zinc.

PROSPECTS ON GOULD ISLAND.

Gould Island, which lies south and east of Sulzer, is about 2 miles long and less than 1 mile wide. It is composed essentially of limestone, siliceous schists, and slate intruded by a diorite mass which occupies the eastern portion of the island. The prospects are at the southwest end of the island. The ore, which consists of galena, sphalerite, and chalcopyrite, occupies small veinlets, and is finely disseminated in a belt of siliceous limestone 30 feet wide, striking east and west, and dipping steeply north. Associated with the ore are calcite, quartz, garnet, epidote, and large amounts of wollastonite, which occurs in the adjacent limestone in radiating masses. A tunnel 70 feet long, driven along the footwall of this mineralized belt, where it is in contact with slate, disclosed scattered occurrences of ore. Just north of the tunnel is an open cut and a shaft, 10 feet deep, exposing mineralized rock of the same character. About 300 feet east of these workings is another open cut and a pit, 10 feet deep, on the same belt. The ore exposed on these claims at the time of the writer's examination, in 1908, was small in amount and of low grade.

PROSPECTS AT HEAD OF COPPER HARBOR.

The prospects at the head of Copper Harbor, indicated on Plate II (p. 28), except the Paris vein, are all contact-metamorphic deposits and lie adjacent to the same granodiorite batholith that is exposed on the Copper Mountain and Jumbo groups. On none of these claims did the developments up to 1908 exceed the assessment work required. On the Paris group of claims, at an elevation of 300 feet, about half a mile from the beach, a tunnel 115 feet long has been driven along a small quartz vein, striking northeastward and carrying a low content of copper and gold. The country rock is a banded quartzite striking N. 40° W. and dipping 40°–60° SW. The Gould group, which lies north of Reynolds Creek, half a mile from Copper Harbor, at an elevation of 300 feet, is located along the contact of the diorite with quartzite, which at this point strikes S. 20° E. A 50-foot tunnel crosses the contact rock and enters the granite, in which also small amounts of chalcopyrite and pyrrhotite are scattered near the contact in fine particles. A 40-foot shaft at the mouth of the tunnel exposes the mineralized garnet-epidote rock, showing a banded structure striking parallel with the contact and dipping 60° SW. About a mile northeast of the Gould group and at an elevation of 100 feet is the Russian Bear claim, and adjoining this on the north is the Texas claim, at an elevation of 1,450 feet. The contact-metamorphic deposits on both these claims flank the western slope of the granodiorite batholith, and the developments consist mainly of open cuts and trenches, in which only small masses of ore have been exposed.

PROSPECTS ON HETTA MOUNTAIN.

Hetta Mountain, which lies southeast of Copper Harbor, is made up essentially of limestone and quartzite, its northern slope, as indicated on Plate V, being bordered by the granodiorite intrusive. Two claims have been located on contact deposits along the intrusive contact about a mile from Copper Harbor, at an elevation of 900 feet. In 1908 the ore bodies had been prospected by three tunnels, one 20 feet, one 25 feet, and one 30 feet in length, and several open cuts in which small masses of chalcopyrite and pyrrhotite are exposed in the garnet-epidote contact rock. The quartz schist country rock on the south, which forms the hanging wall of the deposits, strikes east and west, has a nearly vertical dip, and is intersected by granitic and pegmatitic dikes.

In a gulch at an elevation of 1,380 feet another prospect is located on a vein deposit consisting of garnet with some epidote and sulphide ores in the siliceous schists. Here, at a point where a small mass of chalcopyrite ore is exposed, a tunnel 30 feet long has been driven on the vein. On the ridge of Hetta Mountain the quartzites alternate with beds of limestone which strike N. 80° E., and which are intruded here and there by masses of granodiorite. Along the contact of one of these dikes on the north slope of the ridge, at an elevation of 2,480 feet, there is a contact-metamorphic deposit which contains both the sulphide and the carbonate of copper. A tunnel 15 feet long and considerable stripping constitute the developments and expose small masses of the copper ore in a garnet gangue. Southeast of this prospect, on the opposite side of the ridge, at an elevation of 2,500 feet, an iron capping has been explored by trenches in which also small amounts of copper ore are exposed.

KASAAN PENINSULA.

TOPOGRAPHY.

MAIN FEATURES.

Kasaan Peninsula is a promontory on the east side of Prince of Wales Island that includes about 60 square miles and lies between 132° 5′ and 132° 35′ W. longitude and 55° 25′ and 55° 40′ N. latitude. (See Pl. XIII, in pocket.) Seen from a steamer on Clarence Strait the peninsula appears to be an island, whose summits are highest near its central part and diminish in height toward the north and south. A neck of low land between the head of Kasaan Bay and the south end of Thorne Bay connects the peninsula with Prince of Wales Island. This low pass appears to represent the continuation of a valley, from 8 to 10 miles wide, which is tributary to the north branch of Thorne Bay and extends northwestward through the center of Prince of Wales Island. Kasaan Bay, which is 18 miles long and 1½ to 4 miles wide, occupies the south end of this valley. In the northward extension of this valley and on the low pass south of Thorne Bay there are many small lakes and morainal deposits, which will be mentioned later.

The highest point on the peninsula is the top of Kasaan Mountain (Pl. XIV, *A*), which has an altitude of 2,840 feet. The other mountains average about 2,000 feet in height and their slopes are deeply dissected by small valleys and by narrow steep-sided gulches.

LEVELS OF EROSION.

On Kasaan Peninsula there are many flat areas, some of them containing small lakes, and the mountain slopes themselves are interrupted by benches or terraces (Pl. XIV, *C* and *D*), which occur at different elevations and apparently at rather regular intervals above sea level. These benches represent levels of erosion.

The lowest bench level is indicated by a series of flats or forelands at a height of about 50 feet above sea level. (See Pl. XIV, *D*). Forelands at this height are especially prominent at the head of Kasaan Bay and on the adjacent islands. Along the northern shore of the peninsula and in Tolstoi Bay a higher level of erosion, which seems persistent at 100 to 150 feet on many parts of the peninsula, is marked by wide flats in the valleys, some of which are occupied by small lakes. Such flats occur just north of Grindall Point; on the hills just north of Kasaan; northeast of the Haida mine, where the flat is covered by a lake; on both the east and west slopes of Tolstoi Bay; and southwest of Thorne Bay, where there are two large lakes.

Still higher, at an elevation of 250 to 300 feet, a level of erosion is represented by a flat, occupied by a lake, at the head of Poor Mans Creek, on the divide toward Tolstoi Bay; by flats north of the Alarm claim, on which there are several lakes; and by several areas occupied by lakes northeast of the Haida mine. The surface of the lake just east of Lake Three, at the head of Kasaan Bay, and that of the lake below the Goodro mine are also at this elevation.

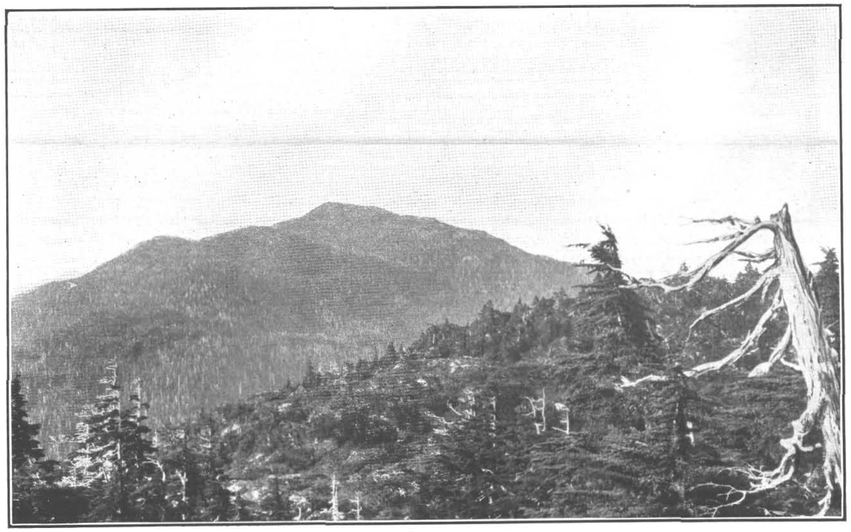
The next or fourth series of benches and flats are prominent at an elevation of about 500 feet above sea level. At this level also there are lakes, from which small streams flow down through gulchlike valleys to lower levels. At this altitude there are terraces along the north slope of the southwest half of the peninsula, flats south of Hadley, a low pass across the peninsula southwest of Lyman Anchorage, and the lakes and flats on the divide from Windfall Harbor to Tolstoi Bay and east of the It mine. Most of the summits of the hills north of the It mine and adjacent to the Salt chucks at the head of Kasaan Bay are at an elevation of about 500 feet.

Higher levels of erosion are indicated at elevations of 1,100 and 1,300 feet by lakes and flats in the central portion of the southeast half of the peninsula, by flats that are in part occupied by lakes on Mount Andrew and on the mountain just west of Lyman Anchorage, and at the head of a branch of Tolstoi River. Other lakes at an altitude of about 1,500 feet north of Grindall Point Mountains and north of Kasaan Mountain may mark a higher erosion level.

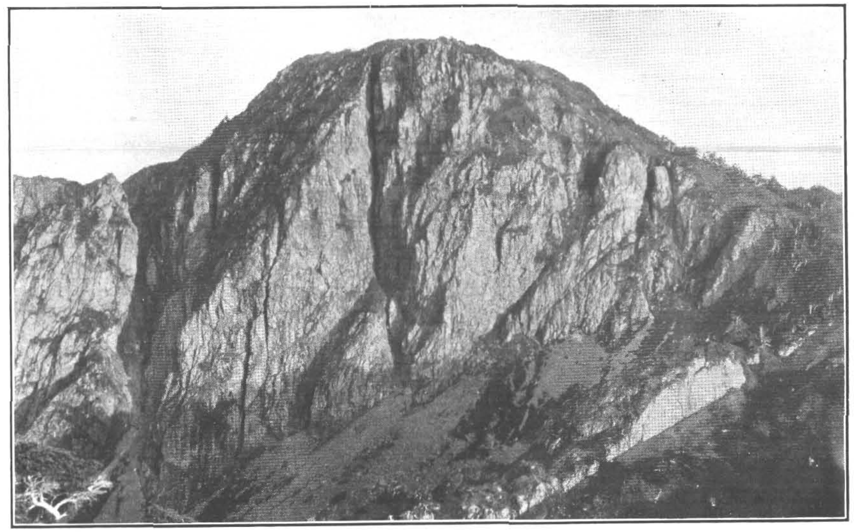
The highest relatively level areas stand at an altitude of about 1,850 feet, on the Grindall Point Mountains, where there are also small lakes, though they are not shown on the map; also on the ridge southeast of Kasaan Mountain and on Tolstoi Mountain.

GLACIATION.

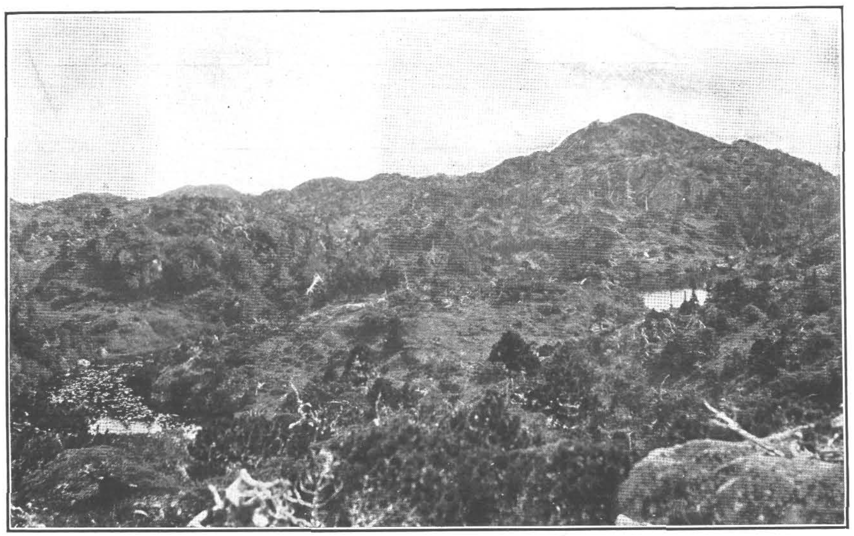
The mountain mass of Kasaan Peninsula exhibits characteristic glaciated topography. That the entire peninsula was at one time overridden by ice streams is evident from the glacial erratics which lie on the highest summits, the moraine deposits which occur on the lower levels, and the many basins which stand at various elevations on the mountain slopes and are now occupied by lakes. (See Pl. XIV, *C*.) During the period in which this area lay beneath the



A. VIEW SOUTHEASTWARD FROM KASAAN MOUNTAIN.

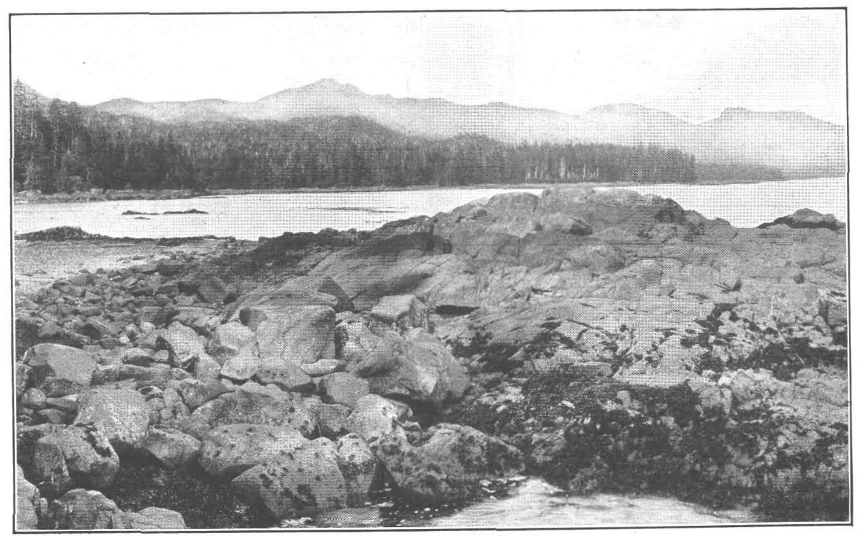


B. NORTH SIDE OF KASAAN MOUNTAIN.



C. TOPOGRAPHY ON SUMMIT OF GRINDALL MOUNTAIN.

Showing small lake basins and scrub pine above timber line.



D. FORELANDS ALONG NORTHEAST SIDE OF KASAAN BAY.

Mountains on Kasaan Peninsula in background. View taken from point at entrance to Salt Chuck at head of Kasaan Bay

ice many of the minor topographic features, such as the earlier erosion level, were partly destroyed. Some of the valleys were more deeply eroded, lake basins were formed, and wide areas of glacial silt and débris were laid down. This section of the ice stream is well represented in the northern extension of the valley of Kasaan Bay, which is occupied by a chain of connecting lakes, on the sides of which thick beds of glacial clay and débris have been exposed by subsequent stream erosion. This valley probably represents a preglacial river floor, and only the lake basins and minor physiographic features can be attributed to ice erosion.

Erosive action subsequent to the ice period has formed the gulches and ravines which are everywhere prominent on the mountain slopes.

Another noteworthy feature of Kasaan Peninsula is its precipitous southwest slope, which is much steeper than that on the northeast. This difference may be due to the fact that the ice stream remained longer in the valley of Kasaan Bay than in that of Clarence Strait, the action of the ice tending to deepen the valley and at the same time to protect the mountain slopes from surface erosion.

FORESTS.

Kasaan Peninsula is densely forested with spruce and hemlock, principally hemlock, which extends to elevations of 1,500 to 1,800 feet. (See Pl. XIV, *C*.) The timber, especially that on the southwest side, toward Grindall Point, is large and straight. The mountain side is steep down to salt water, so that the timber is easily accessible. The mountain summits and ridges above timber line are fairly open and bear relatively little vegetation as compared with that of the densely forested lower levels (Pl. XIV, *D*), groups of scrubby pine and juniper and a low berry bush being the principal plants found.

Prince of Wales Island was included in the Tongass National Forest, but in 1908 that portion of Kasaan Peninsula which lies south of the Hole in the Wall (the boundary line is indicated on Pl. XIII) was taken out of the national forest.

GEOLOGY.

GENERAL FEATURES.

The geology of Kasaan Peninsula displays strikingly the phenomena of igneous intrusion and contact metamorphism. The geologic problems are numerous, but in this report it is possible to consider only the questions that directly bear on the occurrence of ore.

The relations of the geology of the peninsula to that of the Ketchikan mining district have been already described (pp. 16–28). The following discussion will be confined to the stratified rocks, which comprise those of sedimentary and volcanic origin; the intrusive rocks, which apparently underlie the peninsula and consist essentially of granitic and porphyritic rocks; and the ore deposits.

The stratified rocks are of interest to the miner because they determine the character and composition of the ore bodies. The intrusive rocks are of even greater interest because they are believed to be the original source of the ores. As the principal ore deposits are found at or near contacts between certain intrusive and stratified rocks, it is desirable to determine the particular intrusive or intruded rocks with which the ore deposits are most commonly associated.

THE GEOLOGIC MAP.

On the geologic map (Pl. XV, in pocket) an attempt has been made to show the distribution of the stratified and intrusive rocks and to indicate the location of the principal known ore bodies. In the field much difficulty was encountered in determining the geologic boundaries and in recognizing the various geologic formations, some of which are remarkably similar. The mountain sides are heavily timbered and the low levels and flats are covered with a dense growth of vegetation, so that exposures of bedrock are rare and are found principally in the stream gulches and at points along the shore. These meager rock exposures afford the only means of indicating the distribution of the various rock formations in the areas that are covered with vegetation and talus. The geologic sections that accompany the map and show the underground structure of the rock formations are based entirely on inferences from surface observation, except in places where the structure was revealed by mine workings. Future detailed geologic mapping and mining will doubtless disclose many errors in this map, yet the writer believes that it shows with fair accuracy the general distribution of the rock formations and that it may therefore be of use to the miner and to the prospector.

STRATIFIED ROCKS.

CHARACTER AND RELATIONS.

The stratified rocks are principally tuffaceous graywackes interstratified with quartzites, conglomerates, and some limestones. These sedimentary deposits comprise a conformable series of beds several thousand feet thick, all probably of Devonian age. They occur principally in the northern part of the peninsula and have been generally altered by regional and contact metamorphism. It was not possible in the field to subdivide these sediments stratigraphically, so that in this discussion and on the accompanying map they are considered only as to their lithology. Two lithologic types have been recognized in the mapping—(1) a series of clastic rocks, including graywacke, quartzites, and conglomerates, and (2) a series of limestones. The limestones are of the greater economic importance because of the influence they have had on the occurrence of the copper deposits.

Nearly two-thirds of Kasaan Peninsula is occupied by clastic rocks, which in large part consist of a series of metamorphosed sediments, usually epidotized and containing crystals of amphibole or pyroxene. In texture these beds range from fine-grained compact rocks, such as quartzites and graywackes, to coarse conglomerates. As these sedimentary rocks are composed of igneous material, and as they have been greatly altered, they closely resemble massive igneous rocks, though in most places their clastic texture may be recognized, especially on weathered surfaces.

The term Kasaan greenstone was applied to these beds by Brooks in his report on the Ketchikan district in 1901,[1] but detailed study has shown that they are graywackes containing in certain places tuffaceous material. Interstratified with these rocks are narrow beds of limestone, which are entirely recrystallized and contain no traces of organic remains. The relation of these limestone beds to the fossiliferous beds on Long Island, in Kasaan Bay, 1 mile southwest of Kasaan Peninsula, is important and will be discussed later. The stratigraphic succession of these sedimentary rocks is difficult to determine, as the beds are nearly vertical in dip and structurally appear to lie in the form of a synclinorium.

The rocks of this series are described separately, and these descriptions are followed by a discussion of their age and structural features.

GRAYWACKE.

Graywacke is a general term that was used in the field to designate certain obscurely bedded, in places much altered, greenish rocks, which range in texture from distinctly conglomeratic to aphanitic. Some of the finer-grained graywackes can with difficulty be distinguished from igneous rocks. The results of the field study led to the inference that the graywackes consist largely of igneous material worked over mechanically but not greatly decomposed before deposition, and this inference is confirmed by microscopic study. Since their deposition, however, they have been in places greatly changed by shearing, brecciation, and the development of secondary minerals. Some of the most characteristic specimens collected were selected for detailed study. The order in which they are described follows generally their increasing fineness and metamorphism. The degree of metamorphism necessary to convert a certain rock into a graywacke has not been determined or defined, but for those

[1] Brooks, A. H., Preliminary report on the Ketchikan mining district, Alaska, with an introductory sketch of the geology of southeastern Alaska: U. S. Geol. Survey Prof. Paper 1, pp. 49-50, 1902.

specimens studied in thin section in which metamorphism had gone far enough to be readily detected the field name graywacke has been retained. The microscopic examinations and descriptions are the work of H. E. Merwin.

Specimen 129. Graywacke (conglomeratic). The broken surface of this rock has the appearance of an augite lamprophyre; the weathered surface shows bedding and pebbles. In the slide two kinds of pebbles can be made out, one of graywacke, consisting of fragments of augite, hornblende, and feldspar in a dusty chloritic matrix; the other of porphyry, containing large crystals of fresh augite with decomposed feldspar in a groundmass which is chiefly chloritic. Besides pebbles there are angular fragments of porphyry and of minerals derived from porphyry. This angular material and dustlike particles and chlorite form the matrix of the rock.

Specimen 195. Graywacke (conglomerate). In the hand specimens pebbles of porphyritic rocks, the largest several centimeters in diameter, can be distinguished, but their outlines are not clear. Some of these pebbles contain large crystals of hornblende. The thin sections show that the pebbles represent at least five different porphyritic rocks. The matrix consists of fragments of hornblende and feldspar, which are partly chloritized and partly recrystallized as hornblende and epidote. Borders of the secondary hornblende have formed around the original large fragments of hornblende. The rock contains minute veins of secondary hornblende, calcite, epidote, and zoisite.

Specimen 188. Tuff. Megascopically the rock has the appearance of a fine-grained altered hornblende lamprophyre, which contains scattered angular inclusions of a medium-grained leucocratic rock. When moistened the dark parts of the rock also seem to have inclusions. Viewed microscopically the fragmental material appears more angular than that in the rocks already described, and includes abundant broken crystals of hornblende and augite. Much of the matrix is too fine grained for determination. The material as a whole seems to be like that of broken-down but not greatly altered porphyry.

Specimen 196. Graywacke. In the hand specimen this rock looks like basalt, containing minute prisms of hornblende in a much finer grained matrix. Slight magnification of the slide, however, shows clearly the fragmental character of the constituents. Secondary hornblende appears in the matrix and in veins. Epidote accompanies the hornblende in some veins. White mica is the chief alteration product of the feldspar.

Specimen 424. Graywacke. This rock is dark greenish gray mottled with dark red, having a brecciated appearance. The microscope shows that the red patches are fragments of acid porphyries in which phenocrysts of feldspar are contained in a groundmass that is now almost entirely calcite and chlorite. The matrix of the graywacke consists of fragments of feldspar cemented by calcite and chlorite.

Specimen 351. Graywacke. A fresh surface of the rock is dark greenish. The only distinguishable structures are irregular cleavages of hornblende and light aphanitic rounded or subangular patches. A weathered surface is light colored and chalky, with distinct aphanitic patches, the largest 3 centimeters in diameter. Under the microscope the aphanitic material is seen to be aplite, mostly orthoclase, surrounded by hornblende in ragged crystals and granular orthoclase and plagioclase. Epidote and magnetite are abundant. Much of the hornblende appears to be secondary, for the borders of the fragments of aplite are penetrated by the minerals of the matrix.

QUARTZITE.

Prominent beds of quartzite are interstratified with the graywacke. They are of aphanitic texture, are light gray to brown in color, and are highly indurated and brittle. The quartzite at most places contains many cleavage cracks and has a banded structure, which is usually parallel to the main structural lines of the complex. The microscope shows that the quartzite is made up essentially of quartz and a large percentage of feldspar. The rock is an extremely fine textured phase of graywacke, the conglomerates representing the coarse phase.

CONGLOMERATE.

The conglomerate is made up principally of fine to coarse, rounded, waterworn pebbles, though some of the beds contain cobbles and even bowlders. The matrix or cement of this conglomerate is essentially silica and calcite and in certain beds the calcite is most abundant. The pebbles and cobbles are of chert and limestone, those of chert being the more numerous. (See Pl. XVI, *D*.)

LIMESTONE.

Beds of limestone are intercalated with the graywacke and conglomerate. These beds are entirely recrystallized and contain no traces of organic remains. They are of interest because of their association with and relation to the ore deposits, and are indicated separately on the geologic map. They range in thickness from less than 100 to about 600 feet, strike northwestward, and dip to the northeast or to the southwest. At some places the beds are wrinkled and irregularly folded; at others they are brecciated. Dark-colored siliceous beds, from a fraction of an inch to a few inches thick, are interstratified with certain of the limestones, and at some places epidote and garnet have been introduced into the limestones along bedding planes and fractures. (See Pl. XVI, *C*.)

FOSSILIFEROUS LIMESTONES ON LONG ISLAND.

Beds of limestone conformably underlain by feldspathic sandstones and conglomerates occur on Long Island, which is in the central part of Kasaan Bay and lies a mile southwest of Kasaan Peninsula. Interstratified with these limestone beds near their contact with the underlying rocks are narrow beds of sandstone and conglomerate, most of the pebbles in the conglomerate being of porphyry. The limestone beds themselves contain abundant fossils, of Devonian age.

Collections were first made at this locality by A. H. Brooks in 1901. In 1905 a more complete collection was made by E. M. Kindle, who submitted the following report:[1]

Blue limestones form much of the surface outcrops on a group of small, low islands near the middle of Kasaan Bay, of which Long Island is the largest. On Round Island the limestones are not greatly metamorphosed, but have occupied a zone of vigorous deformational activity. The island affords an uninterrupted outcrop of the limestones entirely around its shore line. These outcrops are of particular interest as illustrating in a small area the complex character of the deformation in this region. The beds are everywhere inclined at a high angle, usually about 90°. On the north and east sides of the island the strike is within a few degrees of due north. From nearly due north the strike swings around abruptly to N. 80° E. on the west side of the island. The exposures on the west side show the sharp elbow which the nearly vertical strata make in changing from a northerly to an easterly strike. The limestone on Round Island is shown by its fossils to be of the same age as the upper beds on Long Island, which lie a few hundred yards southeast.

On Long Island, which has a length of about 2 miles and an average width of less than one-half mile, the limestones show a less degree of deformation than those of Round Island. The flexures have comparatively gentle dips, amounting in parts of the southeastern portion of the island to only 5° or 10°. In the western part of the island, however, the dip rises to 90°. The strike, as on Round Island, varies greatly.

A section along the south side of Long Island from the east end to Salt Pond shows the following series of beds

Section 12, Long Island.

	Feet.
c. Hard dark-gray limestone, slightly darker than the preceding	270
b. Hard blue fine-grained limestone, fracturing easily in any direction	200
a. Buff or cream-colored feldspathic sandstone underlying the limestones	90
	560

The two divisions of the limestone series are conformable, and the upper and lower portions are very similar in lithologic character. Analyses of the upper and lower portions of the limestone series show them to be very similar in chemical composition, one carrying 96.11 per cent, the other 97.50 per cent of lime.

Aside from the faunal differences, which are quite marked, there are no very evident reasons for making two divisions of the limestones.

[1] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, pp. 47-49, 1908. See also Kindle, E. M., Notes on the Paleozoic faunas and stratigraphy of southeastern Alaska: Jour. Geology, vol. 15, pp. 324-327, 1907.

Fauna.—The character of the fauna in the lower section (*b*) of the limestone series is indicated by the following list:

Stictopora sp.
Cladopora sp.
Spirifer cf. sulcatus Hisinger.
Sanguinolites sp.
Cardiola sp.
Hercynella nobilis Barr.
Hercynella bohemica Barr.
Holopea sp.
Murchisonia angulata Phillips.
Murchisonia sp. 1.
Murchisonia sp. 2.
Planitrochus cf. amicus.
Loxonema sp.
Holopella sp.
Trochonema sp.
Euomphalopteris? sp.
Operculum.
Beyrichia? sp.
Leperditia sp.
Orthoceras sp.

The occurrence of the genus Hercynella in this fauna is of considerable interest, since it has not been found heretofore in America. *H. bohemica* occurs in the Lower Devonian of the Ural Mountains. Both *H. bohemica* and *H. nobilis* are present in étage F of Barrande's Bohemian section. Their presence in the fauna at Long Island indicates that the latter is much more closely related to the European and Asiatic than to the American faunas outside of Alaska. This lower fauna at Long Island represents the lowest Devonian horizon which has been found in Alaska.

In the upper portion of the higher limestone (*c*) the following fauna is found:

Favosites cf. radiciformis Rom.
Cyathophyllum sp.
Orthophyllum? sp.
Zaphrentis sp.
Calceola cf. sandalina.
Syringopora sp.
Lingula cf. bohemica.
Atrypa reticularis Linn.
Atrypa hystrix Hall.
Gypidula opatus (Barr).
Gypidula cf. intervenicus (Barr).
Meristella cf. barrisi Barr.
Stropheodonta stephani (Barr).
Spirifer sp.
Spirifer hians Bich.?
Spirifer thetidis Barr.
Spirifer subcomprimatus Tsch.
Spirifer sp.
Spirifer indeferens Barr.
Spirifer sp.
Reticularia? sp.
Rhynchonella cf. amalthea Barr.
Rhynchonella livonica Buch.
Pugnax sp.
Dalmanella occlusa Barr.
Schizophora macfarlani Meek?
Schizophora striatula Schloth.
Streptorhynchus sp.
Stropheodonta comitans Barr.
Camarotœchia? sp.
Cypricardinia? sp.
Conocardium cf. bohemicum Barr.
Conocardium sp.
Lucinia cf. proavia Goldf.
Leptodesma sp.
Mytilarca sp.
Nuculites sp.
Telinopsis sp.
Holopella? sp.
Loxonema? sp.
Murchisonia sp. 2.
Murchisonia sp. 1.
Naticopsis sp.
Oriostoma sp.
Oriostoma princeps var. Oehlert.
Euomphalus cf. planorbis D'Arch. and Vern.
Tremanotus cf. fortis Barr.
Tentaculites sp.
Ooceras sp.
Gomphoceras? sp.
Orthoceras sp.
Cytherella? sp.
Entomis pelagica Barr.
Lepterditia sp.
Cyphaspis sp.
Proetus sp.
Proetus cf. romanooski Tsch.

In place of the gastropods, which are the dominant forms in the lower horizon, the brachiopods, are the predominant group of this fauna. The Hercynellas, which are abundant at five horizons in the lower beds, appear to be entirely absent. The upper fauna, however, agrees with the lower in its foreign affiliations. In it occurs the peculiar coral, Calceola, very common in the Middle Devonian of Europe. Several specimens among the brachiopods are either identical with or have their nearest analogy in European species. The fauna represents a Middle Devonian or late Lower Devonian horizon.

The lowest 40 feet of division *c* of the Long Island section furnished a fauna differing but slightly from that of the upper part. The following list indicates its character:

Cladopora?
Cyathophyllum sp.
Camarotœchia sp.
Meristella cf. ceres Barr.
Spirifer sp.
Spirifer cf. thetidis Barr.
Spirifer cf. cheiropteryx.
Stropheodonta comitans Barr.
Orthonota sp.
Schizodus sp.
Conocardium cf. bohemicum Barr.
Euomphalus planorbis D'Arch. and Vern.
Oriostoma princeps var. Oehlert.
Tentaculites.
Cyrtoceras sp.
Orthoceras sp.
Proetus cf. romanooski Tsch.

The stratigraphic relations of limestones of Long Island to the geologic horizons represented on the adjacent shore of Kasaan Bay can not be determined because of their topographic isolation.

These limestones are white to gray in color and are noncrystalline. The change from the sandstone to the limestone is abrupt and the limestone occurs only in the upper part of the series. The beds are in general slightly folded, several changes from anticline to syncline having been noted on the shore of the island; the anticlines forming the bays and the synclines the points. Some faults were observed. At a point on the southeast end of the island the limestone lies in contact with sandstone and though the strike was the same the dip was different, suggesting an unconformity. At other points, however, the conformity of the limestones and sandstones was evident.

The structure of the sedimentary rocks exposed on Long Island is of interest because it shows two systems of folding, an older system of small folds with a northeasterly strike and flat dips to the northwest and southeast, and a later system of broader folds which trend northwest and are parallel to the main structural lines of the Coast Range.

AGE OF THE SEDIMENTS.

Though no fossils were found in the limestones on Kasaan Peninsula, the rocks are regarded as Lower Devonian because of the occurrence of fossiliferous limestones on Long Island interstratified with sandstones and conglomerates. Graywackes and conglomerates which correspond somewhat more closely to those of metamorphosed sediments on Kasaan Peninsula are found on the northwest side of Prince of Wales Island and these lie between limestone beds carrying Lower Devonian fossils.

STRUCTURE.

The structure of the stratified rocks on Kasaan Peninsula is that of a closely folded synclinorium in which the beds in general strike northwest and dip northeast. This structure, however, is interrupted locally by masses of intrusive rock, and where these occur the bedding planes of the stratified rocks are usually parallel with the line of contact of the intrusive mass.

Two prominent joint systems were noted on the peninsula, one striking N. 15°–25° E. and dipping 60°–80° SE., and the other striking N. 50°–70° W. and dipping steeply to the northeast. As these joint cracks traverse the ore bodies and country rock alike they were doubtless developed subsequent to ore deposition, and the fact that most of the basalt dikes follow the prominent directions of jointing indicates that the jointing occurred before the basaltic intrusions. Fault planes and gouge seams were noted in the mine workings, and the ore deposits and the dike rocks have here and there been displaced along these planes. The amount of displacement, however, seldom exceeds a few feet.

DETAILS OF OCCURRENCE.

The rocks exposed along the shore north of Hadley are brown to green quartzites containing some amphibole in finely scattered crystals, highly indurated graywackes containing large hornblende crystals embedded in a fine clastic feldspathic groundmass, and gray to green limestones which are locally cherty in appearance. At some places the limestone beds may be regarded as conglomerates with a calcareous groundmass; at others their groundmass is a dark siliceous material. Rounded pebbles of quartzite and white fine-grained limestone are contained in the conglomerate, and in spots the rock is impregnated with epidote and the groundmass is apparently recrystallized. At Lyman Anchorage the graywacke beds are of a fine granular texture, showing microscopic crystals of amphibole, and in places the rock is finely fractured, the cracks being filled with quartz and epidote, and portions of the rock are impregnated with epidote, which gives it a light-green color.

Farther north, at Windfall Harbor, there are beds of argillaceous quartzite altered to phyllite and biotite schist and hornfels, the alteration being partly due to adjacent intrusive masses. At Palmer Cove the graywackes are much altered and epidotized and intruded by granitic rocks. Veinlets of feldspar, quartz, and epidote are prominent along jointing planes in these rocks.

The rocks exposed on the south arm of Thorne Bay consist largely of fine to coarse conglomerates, which are in places much brecciated, so that their sedimentary nature is disguised. The pebbles and cobbles of these conglomerates consist of graywackes, usually somewhat epidotized and containing hornblende crystals, and of porphyry, chert, and limestone. The rocks at this locality are somewhat less metamorphosed than at other points nearer the intrusive masses.

The graywackes along Tolstoi Creek are more brownish and the conglomerates contain brownish fragments of a slaty rock. These beds are also less altered than the graywackes near the intrusive contacts and are not impregnated with epidote, feldspar, and quartz. The limestones also show less effect of metamorphic action.

The rocks exposed on the west side of the peninsula are essentially graywacke and occasional beds of conglomerate, striking in general northwestward and dipping northeastward. Many of the exposures of the graywacke resemble those of a diorite intrusive mass because of their content of hornblende crystals. Their clastic texture and sedimentary origin were, however, evident on weathered surfaces, especially where the graywacke graded into the coarser phase or conglomerate, and they contained limestone pebbles.

At the Rush & Brown mine the rocks grade from a quartzite of banded aphanitic texture to a graywacke and coarse conglomerate. The conglomerate is highly epidotized and the matrix contains hornblende pyrite. (See Pl. XVI, *D*.) Most of the pebbles are of graywacke, porphyry, and limestone. The graywacke is also somewhat epidotized, especially along cracks. At the Venus claim, 1 mile south of the Rush & Brown mine, beds of conglomerate are interstratified with banded slates and graywackes. The conglomerate contains cobbles of quartzite, slate, limestone, and porphyritic rocks with quartz phenocrysts. The graywackes in general show a slight development of hornblende crystals and contain numerous slaty fragments, though in certain areas where metamorphism was apparently greater the slaty fragments are almost absent and the crystals of hornblende are more abundant. These conditions suggest intense metasomatic action in these somewhat porous rock beds, though the development of schistosity which usually accompanies such metasomatic action is lacking, probably because of the resistance of the rock to differential pressure.

At the Copper Center mine the graywacke is much epidotized and contains large crystals of hornblende associated with chalcopyrite. At the Charles prospect the graywacke and conglomerate grade into the contact rock, and masses of conglomerate are surrounded by the contact rock. A similar alteration of the graywacke is evident at the Brown & Metzdorf prospect, where an ore deposit in the contact rock occurs between a limestone bed and graywacke, showing a replacement of both graywacke and limestone. In all these places the rocks are highly metamorphosed, contain much hornblende, and are impregnated with epidote. The occurrences of contact rock at these prospects indicate the proximity of intrusive rock, which was not exposed on the surface, though its presence is indicated on the map in adjacent areas.

The alteration of the limestone is especially evident along the shore just north of Kasaan, where it is much wrinkled, recrystallized, and has a banded structure. The bands are composed of quartz and epidote and veinlets of epidote and garnet, which protrude on weathered surfaces between the bedding planes, showing still further the alteration of the rocks by mineralizing solutions.

INTRUSIVE ROCKS.

OCCURRENCE AND CHARACTER.

The intrusive rocks that apparently underlie Kasaan Peninsula occupy about one-third of its surface. They invade all the sedimentary strata and are therefore more recent than these stratified rocks. (See map, Pl. XV.) They vary in composition from acidic granite and pegmatite to basic diorite and basalt, and in texture from coarse granular to fine porphyritic rocks. They occur in the form of huge intrusive batholiths, many miles in width, and in dikes, the smallest less than a foot wide. The larger masses are longest from northwest to southeast, parallel with the lines of folding of the stratified rocks. The principal intrusive rock is a diorite, which forms the entire southern part of the peninsula and occupies large areas in its central and northwestern parts. No intrusive rocks earlier than the diorites have been recognized in this region.

Pegmatite dikes intrude the diorites and adjacent metamorphic rocks but are not plentiful. In composition they are nearly like the diorites and were probably derived from the same magma. Porphyritic rocks in the form of dikes, some a few hundred feet wide, also invaded the stratified rocks. The most recent intrusives are numerous small basalt and diabase dikes, which crosscut all the rock formations and the ore bodies.

The intrusive bodies, especially the granitic rocks, are of interest to the prospector, for the principal ore deposits lie at the contacts of the intrusive and the country rock. The main intrusive masses on the peninsula are commonly called granites, though they correspond more closely in composition to diorites. Like the intrusives of the Coast Range, however, this granitic rock varies in composition from a granite to a gabbro, including also syenite, though most of it is diorite.

GRANITIC ROCKS.

GENERAL CHARACTER.

The granitic intrusives include diorite, gabbro, syenite, and a little granite. These intrusives differ considerably in mineral composition and probably represent several periods of igneous invasion during one general epoch, though some of the differences can undoubtedly be attributed to segregation of minerals within the igneous magma while it was becoming solidified.

At the contacts of these granitic batholiths with the country rock there are masses of slightly altered and locally sheared diorite surrounded by unaltered diorite. At some places these masses show sharp contacts, though at others the two kinds of rock merge gradually into each other, suggesting a peripheral solidification of the igneous batholith, a fracturing of its outer part, and subsequent injection of molten rock into the interstices. The igneous mass includes, here and there, angular fragments of highly metamorphosed stratified rocks, some of which can be recognized as included metamorphic rock only because parts of them show parallel lines of flakes of biotite, the remainder of the inclusions having been dissolved by the intruding magma. The schist near the contact also includes, along the bedding planes, feldspar, quartz, and other pegmatitic minerals, suggesting a partial replacement of the intruded beds by igneous material.

DIORITE.

The main intrusive rock of Kasaan Peninsula is a quartz-bearing diorite. The quartz is scarcely more than an accessory, generally forming not more than 5 per cent of the mass. Orthoclase appears in about the same amount. Plagioclase, which makes up 50 to 70 per cent of the rock, is basic andesine, ranging chiefly from Ab_3An_2 to Ab_1An_1. The range of the composition of the individual plagioclase crystals is about the same. For this reason zoning is not pronounced. Twinning according to both the albite and the Carlsbad laws is very common in the plagioclase. Hornblende is everywhere present, constituting 10 to 35 per cent of the weight of the rock. It is the common variety; it is pleochroic in various yellow-greens; it is optically negative, showing a large optic axial angle; its maximum extinction angle, measured from the trace of the cleavage, is from 20° to 25°, corresponding to an angle of 15° to 20° on (010); and its indices of refraction are considerably higher than those of other recorded measurements, namely from 1.665 to 1.680, determined by the immersion method. Some facies of the diorite contain about 15 per cent of yellow-brown or orange-brown biotite. The rock contains small amounts of augite, less than 10 per cent. The minor accessories are apatite, titanite, and magnetite.

The mineral composition, summarized from a study of 16 slides made of rock taken from different parts of the peninsula, shows that the rock contains too little quartz and orthoclase and that its plagioclase contains too much lime to justify its classification with the granodiorite that is so common on the Pacific slope of North America. According to Lindgren [1] this grano-

[1] Lindgren, Waldemar, Granodiorite and other intermediate rocks: Am. Jour. Sci., 4th ser., vol. 9, pp. 269-282.

diorite contains an average of about 23 per cent of quartz, 14 per cent of orthoclase, and 44 per cent of plagioclase (near Ab_2An_1).

Some of the extreme types of the diorites of Kasaan Peninsula are described below. The numbers refer to slides and specimens in the collection of the United States Geological Survey, the full catalogue designation bearing the prefix "7. C. W."

173. Hornblende diorite, from about 4 miles northwest of Hadley. In hand specimen the rock is seen to consist megascopically of plagioclase, hornblende, quartz, magnetite, pyrite, and titanite in a medium-grained groundmass, the bulk of the crystals being between 1 millimeter and 5 millimeters in diameter.

The microscope shows that the rock contains about 55 per cent of plagioclase (Ab_1An_1), 35 per cent of hornblende, 5 per cent of quartz in poikilitic masses, and 5 per cent of accessory magnetite, apatite, biotite, and titanite. In the main the order of crystallization was plagioclase, magnetite, hornblende, and quartz.

135. Hornblende diorite, from the southeastern point of Kasaan Peninsula. Although this is mainly a medium-grained granitic rock, it appears coarse grained on account of its large content of poikilitic masses of hornblende and plagioclase.

Under the microscope the plagioclase, which makes up 60 to 70 per cent of the rock, is found to be about Ab_3An_2. Hornblende, which forms about 25 per cent of the rock, occurs partly in prisms among the feldspar and partly in poikilitic masses inclosing plagioclase. The prisms of hornblende are much lighter in color than the poikilitic masses. Quartz and microcline are very subordinate constituents.

199. Hornblende diorite of medium-grain granitic texture, from a large intrusive mass in the northern part of the peninsula. In the slide the following minerals are found in about the proportions stated: Basic andesine, 70 per cent; hornblende, 15 to 20 per cent; quartz, 5 to 10 per cent; biotite, 5 per cent; accessories, 3 to 5 per cent. Near the contact this rock (specimen 201a) contains phenocrysts of hornblende and plagioclase, the hornblende in many places having nuclei of corroded augite. Augite is very much more abundant in parts of this diorite that have cooled more rapidly than the main body of the intrusive, and particularly in the diorite porphyries to be described later.

106. Biotite diorite of medium grain, from a point near the central part of the peninsula. It contains about 60 per cent of plagioclase (Ab_3An_2), 5 per cent of orthoclase, and 35 per cent of dark minerals, of which biotite is somewhat more abundant than either of the other two essential constituents, hornblende and augite. Magnetite is intergrown with the augite.

GABBRO.

Near some of its margins the diorite becomes basic and passes into gabbro, the hornblende giving place to augite, and the plagioclase becoming richer in lime. Specimens from the mines and prospects north of Karta Bay illustrate this transition.

411. Augite gabbro lamprophyre. This is a melanocratic, porphyritic, medium to coarse grained rock, containing phenocrysts of augite, the larger bordered with primary hornblende and uralite. Many of the smaller phenocrysts are chloritized on the outside and serpentinized within. The groundmass consists of plagioclase (Ab_2An_3), common hornblende, and biotite. Both hornblende and biotite are in part later than the feldspar. The accessories, which crystallized early, are iron ores, apatite, and titanite.

254. Augite gabbro. In the hand specimen this rock is nearly black, medium or fine grained, granitic, and contains visible augite, magnetite, and biotite.

In the thin section the augite is seen to be hypidiomorphic, the distinctly pleochroic grains constituting about 55 per cent of the rock mass. A strongly pleochroic yellow-brown biotite makes up about 25 per cent of the rock and iron ores, in part later than the pyroxene, form 10 to 15 per cent. The biotite is later than both the augite and the magnetite. The spaces among these minerals are filled with much-altered plagioclase. A rock similar to this (specimen 246), much brecciated and impregnated with bornite and chalcocite, is worked as an ore of copper.

SYENITE.[1]

Most of the syenitic rocks occur in dikes and are of porphyritic texture. They are therefore described under the heading "Porphyritic intrusives" (p. 77). Syenite occurs, however, in batholithic masses, principally as a differentiation product of the dioritic magma. The rock shows a preponderance of soda over potassium, as would be expected in a rock derived from a dioritic magma.

43. Albite syenite, from a dike near the head of Hole in the Wall. This is a fine-grained granitic rock, ranging in color from gray-green to red. Its chief mineral is nearly pure albite showing a maximum extinction angle of 16°. The minor constituents are orthoclase (15 to 20 per cent) and biotite (about 10 per cent). Apatite, titanite, and magnetite are accessories, apatite being especially abundant. Although the texture of the rock is granitic, the biotite was in part the last product of crystallization. The rock contains scattered grains of primary calcite and veinlets of secondary calcite.

116. Albite syenite, from a point 1½ miles southeast of Boggs Landing. This type is a light-greenish aphanitic rock that shows in the thin section a fine-grained granitic texture. About 90 per cent of it is albite having a mean refractive index of about 1.530, showing the presence of about 15 per cent of dissolved orthoclase. The rock contains about 10 per cent of quartz but little or no ferromagnesian minerals. This rock and No. 259 are the most alkalic rocks collected from Kasaan Peninsula.

GRANITE.

A second phase of the differentiated diorite magma consists of rocks rich in both alkali feldspars and quartz. Between these rocks and the highly alkalic rocks previously described there are transitional forms, such as the first of the types described below. The more quartzose rocks are in general later and smaller in bulk than the highly feldspathic rocks.

64. Soda granite, from one of the longest granite masses, about 4 miles south of Hadley. This rock is light greenish gray, is medium grained, and consists of visible quartz, plagioclase, and biotite.

In the thin section the proportions of the minerals are seen to be about as follows: Albite, 70 per cent; quartz, 20 per cent; biotite, 10 per cent. The composition of the albite is about $Ab_{15}An_1$, as shown by its refractive index and extinction angle. The accessory minerals are apatite and magnetite.

396. Soda granite, from a dike north of Karta Bay. A light greenish-gray and medium-grained granitic rock. The minerals distinguishable in the hand specimen are quartz, plagioclase, chlorite, epidote, magnetite, and pyrite.

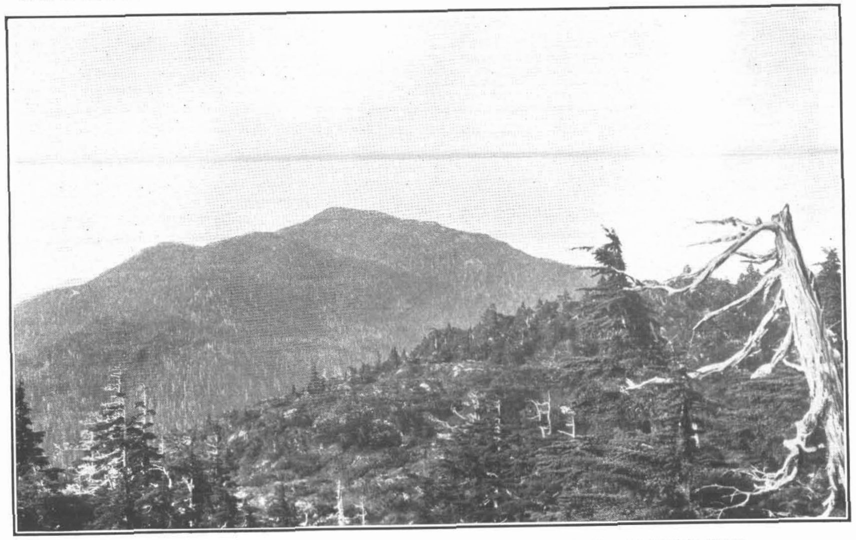
In the thin section the quartz (25 to 30 per cent) is mainly interstitial. The plagioclase has the optic properties of nearly pure albite. These two minerals make up about 98 per cent of the rock. The chlorite is derived from biotite, and epidote has come from the small amount of lime-bearing plagioclase.

39. A medium to coarse grained red granite from a point 1 mile north of Hadley, consisting almost exclusively of light-colored constituents, perthitic orthoclase, and quartz in about equal amounts. The dark constituent is biotite. This is the most acidic intrusive rock collected from the peninsula.

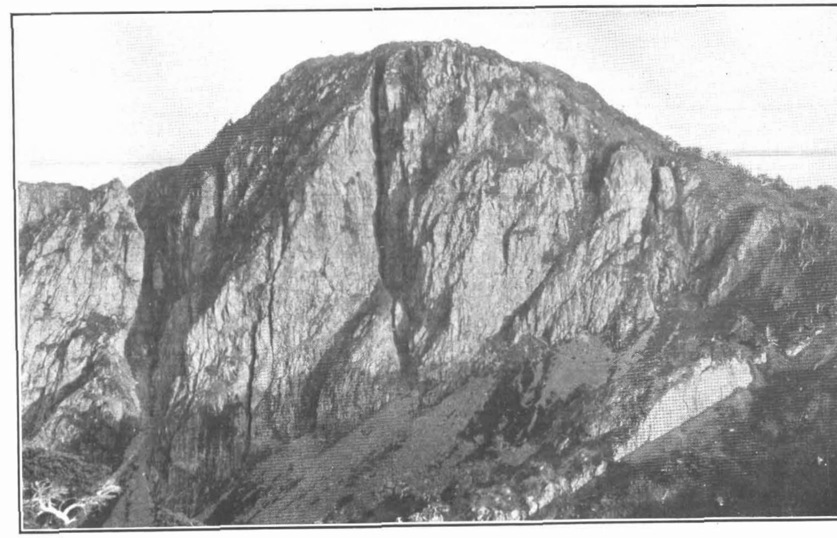
DETAILS OF OCCURRENCE.

The granitic intrusives which compose Grindall Island, at the southeast end of Kasaan Peninsula, are much segregated and fractured. The segregations are essentially masses of basic hornblende locally showing radiating crystals of hornblende a few inches in length. In places the rock grades from coarse-grained to fine-grained diorite within a short space and at other places it appears to have been fractured and the fractures, most of them rather wide, filled with diorite of fine or coarse texture. At certain points a gneissoid banding or flow structure was noted in the intrusive mass and between the bands are irregular masses of a coarse basic

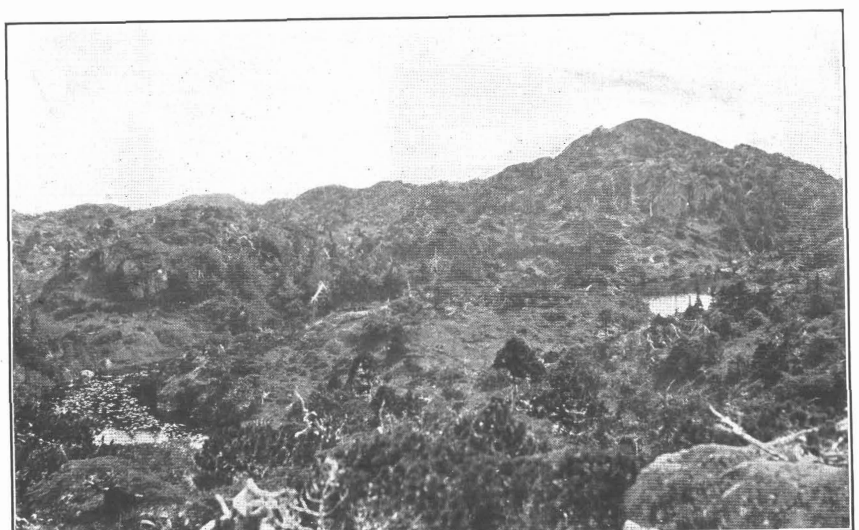
[1] Petrographic microscopic descriptions by H. E. Merwin.



A. VIEW SOUTHEASTWARD FROM KASAAN MOUNTAIN.

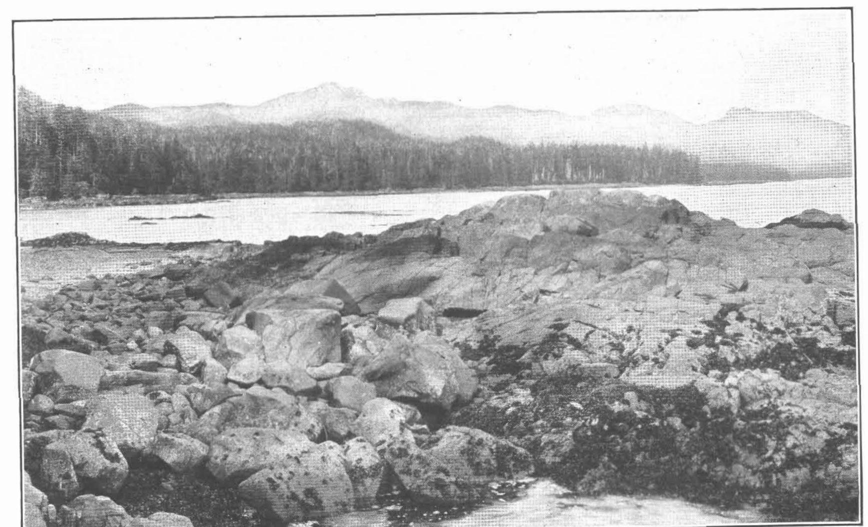


B. NORTH SIDE OF KASAAN MOUNTAIN.



C. TOPOGRAPHY ON SUMMIT OF GRINDALL MOUNTAIN.

Showing small lake basins and scrub pine above timber line.



D. FORELANDS ALONG NORTHEAST SIDE OF KASAAN BAY.

Mountains on Kasaan Peninsula in background. View taken from point at entrance to Salt Chuck at head of Kasaan Bay

diorite a foot or more in diameter. These phenomena near the contact of the largest intrusive mass on Kasaan Peninsula seem to show that there was a lack of uniformity in the composition of the original magma at the time of its intrusion and that after the first intrusion and consolidation fracturing occurred and additional magma was forced into the fractures. A further consolidation, accompanied by fracturing and by the introduction of magmatic solutions, may account for the pegmatitic and aplite and alaskite dikes which are most common in the granitic rocks near the contact. (Pl. XVI, *A*, *B*.)

At Lyman Anchorage the granitic intrusive at the contact is gneissoid, the structure striking N. 20° E. and the dip being vertical, parallel to the contact. This dioritic rock is cut by veins and dikes, the largest 100 feet wide, of orthoclase quartz pegmatites or alaskites, and some of the veins grade into quartz veinlets a few inches thick. Most of the minerals in these dikes and veins are coarsely crystalline. At the contact the intruded rocks have been altered to an amphibole schist, so that the line between the intrusive and intruded rock is not always clearly defined. A short distance away from the contact the intrusive rock is diorite of uniform texture, though it contains inclusions of basic diorite and amphibolite. These inclusions as well as the diorite some distance from the contact are cut by the pegmatitic dikes.

The main diorite mass on Tolstoi Mountain, at the north end of Kasaan Peninsula, is almost identical in composition and character with that at Grindall Point, and around its contact similar phenomena were observed. A typical specimen (No. 199) from Tolstoi Mountain has already been described (p. 75).

The gabbro is limited to the mass that includes the Goodro mine and extends northwestward beyond the Rush & Brown mine, but only part of this mass is actually gabbro. The western part of this intrusive mass, which is indicated on the map (Pl. XV), is made up of normal diorite. The eastern part of the mass is a coarsely crystalline augite gabbro (see descriptions of specimens 411 and 254, p. 75), sufficiently rich in magnetite to deflect the compass. At the Goodro mine the gabbro is cut by dikes of diorite and pegmatite, so the gabbro is somewhat older than the diorite. Both the gabbro and diorite are altered in places and contain epidote and calcite. At this mine a great number of dikes and veins of feldspar and quartz, many of them containing coarse crystals of amphibole, lie near the ore body.

Near the Rush & Brown mine the diorite contains numerous inclusions of the gabbro, which is therefore the older. Here also the gabbro and diorite are cut by dikes and veins of pegmatite and have been somewhat altered by the mineralizing solutions that deposited the epidote, calcite, and pyrite.

Granitic intrusive of the syenite type was found near the contact of the large intrusive mass at Boggs Landing. Granitic intrusive having a porphyritic texture occurs in large dikes and is described under the heading "Porphyritic intrusives" (below). At many places syenite forms a part of the granitic intrusive masses near their contacts and is merely a phase of the general dioritic mass. The syenite, however, contains inclusions of diorite and fills fractures in the diorite and is therefore regarded as of somewhat later intrusion that the diorite, though in all other features the two types of rock are identical.

The granites, which are also regarded as a phase of the dioritic intrusives, are similar in occurrence to the syenites. At a point 4 miles southeast of Hadley there is a mass of granite nearly half a mile wide, and at a point a mile northwest of Hadley, at the contact of a large mass of diorite, there is a similar granitic mass. A third and larger mass of granite lies north of Karta Bay. The rock of this mass, however, is rich in plagioclase and approaches a quartz diorite in composition. The features of the occurrence of these granitic masses are the same as those of the diorite.

PORPHYRITIC INTRUSIVES.

GENERAL CHARACTER AND DISTRIBUTION.

In general the porphyritic rocks occur in the form of dikes that are from 10 to 100 feet wide and stand nearly vertical. Most of these dikes strike north to northwest but some strike nearly east. In color the porphyries are greenish to pinkish and generally show well-developed though closely crowded feldspar crystals. The phenocrysts are principally plagioclase feldspar and augite or hornblende, the groundmass being microgranular and made up essentially of feldspar and some quartz. The porphyries are generally of syenite, those of granite diorite being scarcer. Ore deposits occur at the contacts of some of the larger porphyry dikes, and although most of them are commercially unimportant they are of geologic interest and are described under the heading "Copper ores" (p. 85). The distribution of the porphyries is shown on the geologic map (Pl. XV).

DIORITE PORPHYRIES.

It was not generally possible in the field to distinguish the diorite porphyries from the related syenite porphyries. In fact, the diorite porphyries form a transitional group between the diorite, the syenite porphyries, and the granite porphyries.

In these porphyries quartz, orthoclase, and augite are more abundant than in the diorite, and the plagioclase is more sodic. Some of the diorite porphyry dikes are more basic near the contact. A dike 60 feet wide, on the east side of Tolstoi Bay, contains in its central part about 40 per cent of hornblende, which is mostly in phenocrysts associated with plagioclase but is partly in the groundmass with about equal amounts of quartz, orthoclase, and plagioclase (specimen 222). A specimen taken near the contact (specimen 223) contains about 65 per cent of hornblende, mostly in the fine-grained groundmass.

But few of the specimens of diorite porphyry examined were fresh enough to warrant more definite statements concerning their original mineral composition than have already been made. The two specimens described below, taken from places near the coast about one-fourth of a mile west of Hadley, are comparatively fresh.

Specimen 46. Augite diorite porphyry. The hand specimen is a dark-gray medium-grained porphyritic rock with abundant phenocrysts of plagioclase and augite, the augite presenting many glistening cleavage surfaces and crystal faces.

In the thin section the plagioclase is seen to be twinned according to both the Carlsbad and albite laws, and its composition was determined as about Ab_1An_2. The augite phenocrysts are in part glassy, clear, and faintly colored, and are in part uralitized. Some augite crystals are surrounded by primary hornblende. The groundmass consists of plagioclase, augite, hornblende, biotite, orthoclase, and quartz. Orthoclase is intergrown with quartz. Apatite and magnetite are abundant, the apatite forming numerous trellis-like structures composed of long, slender needles, structures so frail that it is difficult to understand how they could have been preserved while the rock was in process of solidification. The plagioclase forms about 50 per cent of the rock, and the dark constituents 35 per cent.

Specimen 48. Diorite granophyre. This is a dark reddish-gray rock, fine grained and porphyritic. The phenocrysts are strongly zoned plagioclase, ranging in composition from basic andesine through oligoclase, the interiors being most calcic. The groundmass consists essentially of plagioclase, quartz, and orthoclase, the last two minerals being intergrown as micropegmatite. Quartz and orthoclase occupy about 25 per cent of the area of the slide; dark silicates, hornblende, and biotite, less than 10 per cent. Magnetite, titanite, and apatite are accessories.

SYENITE PORPHYRIES.

Most of the syenitic rocks are of porphyritic texture, but some are granitic. They occur in dikes and contain the highly alkalic differentiation products of the diorite magma. These alkali rocks form a series that stands between two extreme types, one highly potassic, the other highly sodic. The mass of the sodic type is much the greater, judging from the relative abundance of the specimens of the two types collected. Soda should preponderate in the syenites on account of the relatively high soda content of the diorite from which they were derived.

Specimen 259. Calcite syenite porphyry, from a dike near the head of Karta Bay.

In the hand specimen the rock is light yellowish gray, fine grained, and porphyritic. Equidimensional phenocrysts of faintly greenish feldspar about 3 millimeters in diameter form about 2 per cent of the rock; other phenocrysts of rhombic habit, about 0.5 millimeter in diameter, make up a larger percentage. On weathered parts of the rock the phenocrysts have been dissolved and the cavities filled with limonite. The phenocrysts effervesce freely in hot dilute hydrochloric acid, and therefore appear to be ferruginous calcite. Weathered surfaces of the rock are chocolate-colored, and broken surfaces of weathered parts are light brown specked with dark brown.

In the thin section the rock is seen to be holocrystalline. The phenocrysts of feldspar have symmetric extinction angles of albite twins as high as 16°, and refractive indices of about $\alpha=1.529$, $\gamma=1.537$. These angles and refractive indices point to albite. The borders of the phenocrysts show the effects of resorption and subsequent renewed growth. The latest material appears to have been crystallized contemporaneously with the groundmass, as shown by interpenetration. The calcite phenocrysts occur as euhedral crystals, having the habit of the unit rhombohedron. By a geometric analysis of three slides these crystals were found to make up 3 to 6 per cent of the rock mass. Small calcite rhombs are included in the albite phenocrysts, showing that the calcite was the earliest of the essential constituents to crystallize. The refractive index ω of the calcite is 1.742 ± 0.003. For pure calcite $\omega=1.658+$. The high refractive index of the phenocrysts must be due to the presence of siderite.

The groundmass consists of sheaf-like aggregates of finely fibrous feldspar. A few of the coarser fibers, possibly phenocrysts, exhibit albite twinning and an observed maximum symmetric extinction of 17°. The refractive indices α and γ are 1.524 and 1.531. From these facts alone it would be difficult to decide whether the feldspar should be considered as soda orthoclase or as a potash-rich albite. Too little is known of the relation between chemical composition and the refractive index of the soda-potash feldspar to make one the basis for estimating the other. No feldspar of lower refractive index was found in the slides. Interstitial quartz occurs in small isolated patches and probably as thin films among the feldspars. Its bulk is estimated at 5 per cent or less. From 2½ to 3 per cent of calcite is scattered through the groundmass in minute rhombs, either singly or clustered. The accessory minerals, each amounting to less than 1 per cent, are muscovite, apatite, possibly zircon, and a fibrous mineral having the general optic properties of a yellow-green amphibole.

An analysis of this rock by R. C. Wells has been calculated into normative minerals according to the methods of the quantitative system, except that, the lime being insufficient to combine with the CO_2 to form calcite, FeO was used to form siderite. In classifying the rock siderite was grouped with calcite.

The ratio of calcite to siderite calculated from the analysis is lower than would be inferred from the refractive index of the calcite phenocrysts. It is possible that the small rhombs of calcite in the groundmass are richer in iron than the phenocrysts.

Chemically and texturally the rock is a distinctly new type. Chemically, however, it can be made to conform to the quantitative system of classification by changing the method of calculating the minerals as described above. Texturally, the occurrence of calcite in euhedral crystals in an igneous rock is unique. There can scarcely be any doubt that the calcite crystallized directly from the magma. According to Adams and Barlow,[1] primary calcite has been found in granular form in igneous rock. The rocks described by them do not contain free silica, as this rock does.

Analysis of calcite syenite porphyry.

[By R. C. Wells.]

SiO_2	63.41	ZrO_2	0.04
Al_2O_3	16.86	CO_2	2.93
Fe_2O_3	None.	P_2O_5	.12
FeO	2.88	SO_3	None.
MgO	Trace.	Cl	None.
CaO	1.47	S	.05
Na_2O	7.38	MnO	.28
K_2O	3.09	BaO	None.
H_2O-	.29		
H_2O+	.42		99.48
TiO_2	.26		

[1] Adams, F. D., and Barlow, A. E., Geology of the Haliburton and Bancroft areas, Ontario: Geol. Survey Canada, Mem. 6.

Calculated mineral composition.

Corundum	1.06	Apatite	0.34
Quartz	8.74	Rutile	.26
Orthoclase	18.35	Water	.71
Albite	62.35		
Calcite	2.30		99.21
Siderite	5.10		

This calculated composition corresponds to nordmarkose.

Specimen 291. Augite trachyte, from a point near the head of Karta Bay. This is a greenish-gray medium-grained porphyritic rock containing abundant tabular phenocrysts of orthoclase arranged in flow structure. Augite forms phenocrysts and is a chief constituent of the groundmass. Magnetite is easily recognized by means of a lens.

Under the microscope the orthoclase phenocrysts appear to make up about 50 per cent of the mass of the rock. They are fresh and almost glassy, much resorbed, and hold inclusions of augite, plagioclase, and magnetite. One slender crystal is bent in an arc of 9°. The bending has not caused perceptible fracture, but the positions of extinction instead of being turned 9° are turned 13° on the convex side and 6° on the concave side of the crystal. From determinations of the refractive indices of the orthoclase (made by methods based on immersion) it appears to be a nearly pure potash feldspar ($\alpha = 1.517 \pm 0.001, \gamma = 1.525 \pm 0.001$). The extinction on 010 is 7° and the optic axial angle near the maximum for orthoclase. Augite in crystals of various sizes makes up about 30 per cent of the mass of the rock. Biotite that is altered to chlorite and some epidote, a very minor constituent, were formed later than the augite and orthoclase. The groundmass consists of almost completely altered plagioclase, the crystals having been originally not much smaller than those of the phenocrysts. Muscovite and epidote are the chief present constituents of the groundmass. The freshness of the orthoclase and augite and the very far advanced alteration of the plagioclase and biotite are remarkable. All the observed extinction angles of the plagioclase were less than 13°, so that it is nearly pure albite.

Syenite lamprophyre dikes, consisting largely of ferromagnesian minerals with subordinate alkali feldspars, were intruded at the same general period as the syenites. Such dike rocks bear the same relation to the syenites that the gabbros bear to the diorite, with the exception that the gabbros consolidated as marginal facies of the diorite, where they had accumulated during differentiation. While the gabbros were in process of consolidation the forces that caused fissuring were not strongly active, but while the lamprophyres were consolidating these forces must have been nearly at their period of greatest activity. Specimen 108, from a dike cutting albite syenite, contains about 40 per cent of augite in phenocrysts, 15 per cent of hornblende, 10 to 15 per cent of chlorite, a little calcite, and 30 per cent of albite. Specimen 250 contains about 70 per cent of ferromagnesian minerals (now chiefly uralite and epidote) and 30 per cent of orthoclase.

GRANITE PORPHYRIES.

35. Quartz porphyry, from a dike about 2 miles northwest of Hadley. This rock is nearly white and translucent, containing scattered phenocrysts of quartz in a very fine grained groundmass of plagioclase, quartz, and muscovite. The phenocrysts have been considerably resorbed.

769. Granophyre, a dark-red fine-grained rock from a dike in Stevenstown tunnel. A first generation of albite in scattered crystals was followed by a second generation of albite in abundant idiomorphic crystals. The groundmass is micropegmatitic, quartz being intergrown with both orthoclase and plagioclase. Muscovite, biotite, and hornblende are accessories. Primary calcite appears in this rock in two forms, first, as an early crystallization in distinct rhombs included in the albite; second, in interstitial intergrowth with quartz as a final crystallization.

AGE OF THE PORPHYRIES.

The porphyries are presumably younger than the granitic intrusives because of their relation to these intrusives in composition and occurrence. The syenite porphyries at least are older than the ore deposits, for many of the contact ore bodies lie at their contact. Such ore deposits were not noted at the contact of the diorite porphyry dikes, which crosscut the syenite porphyries and hence are younger than the syenites.

PEGMATITES, ALASKITES, AND APLITES.

GENERAL FEATURES.

Dike or vein rocks that are made up essentially of feldspar and quartz—such as the pegmatites, aplites, and alaskites—are not plentiful on Kasaan Peninsula and are found only at places near the periphery of the large granitic intrusive masses. At these places such dikes cut both the large intrusive masses and the intruded sedimentary rocks. They occupy narrow seams and large fissures and strike in various directions, following no particular systems of fracturing. In mineral composition these rocks consist essentially of orthoclase, some albite, and quartz. The coarsely crystalline types are known as alaskites and pegmatites, whereas the fine-grained rocks of practically the same composition are called aplites. Only two specimens of these rocks, representing a somewhat peculiar type, are described here.

PETROGRAPHIC DETAIL.

Specimen 137. Calcite alaskite aplite, a fine-grained light-pink rock, when examined microscopically, was found to consist of about 60 per cent of orthoclase, 30 per cent of quartz, 9 per cent of primary calcite, and a little plagioclase. The red color of the rock is due to dusty hematite sprinkled through the feldspar. The rock is very fresh. (See Pl. XVII, *C*, *D*.)

Two periods of crystallization can be made out. In the first period quartz, orthoclase, and a little calcite formed an even-grained mass penetrated by spider-like stringers of the mother liquor. In the second, the mother liquor solidified in a partly granular, partly poikilitic mass. Orthoclase and calcite are much more abundant in the later crystallization, and the calcite is coarser grained and anhedral.

The proportion of orthoclase to plagioclase is much greater in this rock than in any other examined.

Specimen 767. Alaskite aplite. This rock, taken from a dike 1 inch wide in the Stevenstown tunnel, contains 10 to 15 per cent of albite, 40 to 50 per cent of orthoclase and microcline, and 30 to 35 per cent of quartz. The dike cuts syenite. From the broken phenocrysts in the syenite parallel growth of feldspar has taken place in the dike, indicating that the temperature of the dike was not very different from the temperature of the syenite when the dike was intruded. The feldspar of the syenite is considerably altered by weathering, but that of the dike is still fresh. It is this difference in alteration that makes it possible to trace the boundary of the dike through optically continuous crystals.

AGE.

Their composition and their mode of occurrence as fillings of small and wide cracks having various courses, in both the intrusive and intruded rocks, suggest, as has often been pointed out by geologists, that the magma which formed these dike rocks was injected soon after the intrusion of the diorites and that the fissures they fill are contraction cracks caused by the shrinkage that accompanied the cooling and crystallization of the igneous intrusive masses.

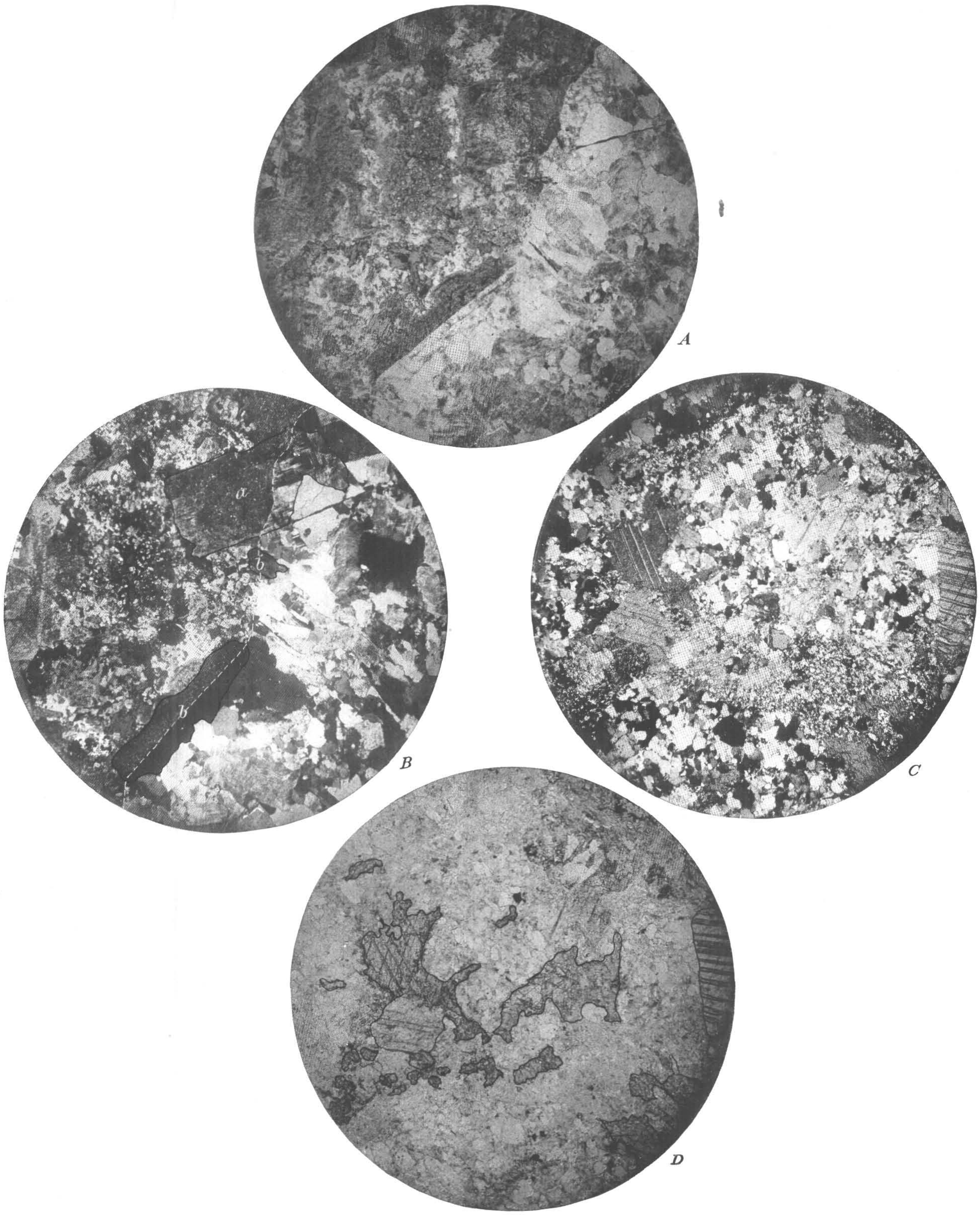
The rocks of this group are assumed to have been derived from the same magma that furnished the granitic intrusives and to have been formed from aqueo-igneous solutions that contained more water than the diorite magma.

The age of the pegmatite and aplite as compared with that of the porphyries is not shown by intersection, but the intimate relations of the granitic intrusives to the pegmatite and aplite when compared with the relations of these intrusives to the porphyries show that the porphyries are younger than either the granitic intrusives or the pegmatites and aplites.

PLATE XVII.

A, *B*. Microscopic views of alaskite aplite (specimen 767, see p. 81). *A*, Section showing contact of an alaskite aplite dike (lighter area) with syenite. *B*, Same section under crossed nicols, showing optical continuity between the crystals of microcline (*a*) and of orthoclase (*b*) in the syenite and the aplite. Dotted line indicates line of contact.

C, *D*. Microscopic views of calcite alaskite aplite (specimen 137, see p. 81). *C*, View under crossed nicols, showing texture. Early crystallization is indicated by the coarse granular texture and later crystallization by the areas of calcite (outlined) and the fine-grained texture. *D*, Same section without nicols crossed, showing areas of calcite.



THIN SECTIONS OF ALASKITE-APLITE AND CALCITE-ALASKITE FROM KASAAN PENINSULA.

CONTACT ROCK.

GENERAL FEATURES.

The name "contact rock" is applied to the metamorphic rock that occurs in zones around the granitic intrusive masses and that has at many localities replaced the granitic rock. In composition it consists mainly of garnet, diopside, and feldspar, but it contains also hornblende and tremolite and some calcite. It includes masses and disseminated particles of sulphide minerals and masses of magnetite containing sulphide ores. A sample of this rock (specimen M1) taken for chemical analysis is described below.

PETROGRAPHIC DETAIL.

Specimen M1. Rock from contact zone between the limestone and the intrusive rock at the Mamie mine, 1¼ miles south of Hadley.

The chemical analysis, made by George Steiger, shows that this rock has the composition of a monzonite rich in lime. The intrusive rock at the Mamie mine goes under the field name of syenite, but an examination of six thin sections from several drill cores of the partly altered intrusive rock shows that considerably less than half the feldspar is orthoclase and that the plagioclase is basic oligoclase and acidic andesine. The rock contains also a small amount of quartz. The ferromagnesian minerals are much subordinate to the feldspar. The mineral composition therefore shows that the rock is a monzonite, and that it is part of the intrusive mass. Its slightly higher content of lime than most monzonites is probably due to lime brought in from the adjacent limestone.

The rock consists of about 50 to 60 per cent of plagioclase (albite and oligoclase), 10 per cent of orthoclase, 20 per cent of epidote, and 10 to 15 per cent of calcite. It contains also a lath-shaped mineral, confined chiefly to secondary veinlets, which is somewhat unlike ordinary rock-making minerals. Its index of refraction ranges from 1.58 to 1.625, its optic axial angle is large, optical character positive, birefringence rather strong, extinction parallel or nearly so, and elongation positive. These characters agree very well with pectolite or prehnite.

In the hand specimen the rock is greenish gray in color and aphanitic.

Analyses of monzonites from Kasaan Peninsula, Alaska (A), and from Babcock Peak, Colo. (B).

[Analysis A by George Steiger; B by H. N. Stokes.]

	A	B		A	B
SiO_2	58.87	57.42	TiO_2	0.59	0.86
Al_2O_3	17.12	13.48	CO_2	.84	None.
Fe_2O_3	1.96	3.74	P_2O_5	.20	.36
FeO	.95	2.10	Cl	....	.03
MgO	1.75	1.71	S	.09	None.
CaO	8.00	6.84	MnO	.10	.09
Na_2O	4.64	4.52	BaO	.06	.15
K_2O	4.34	3.71	SrO	.02	.08
H_2O-	.13	.28	Li_2O	....	Trace
H_2O+	.81	.08			

DIABASES AND BASALTS.

GENERAL CHARACTER.

The more basic intrusive rocks, as well as the most recent, are essentially diabase and basalt. These rocks form dikes that range in width from 1 foot to many feet, in texture from microgranular to coarse granular, and in color from dark green to black. The dikes cut the country rock at many places and penetrate the joints in the granitic intrusives. They also cut the ore deposits in most of the mine workings. The diabase dikes are generally larger, more coarsely crystalline, and older than the basalt dikes, which are cut by the diabase dikes.

PETROGRAPHIC DETAIL.

Specimen 265. Hornblende dolerite. This rock, from the north shore of Karta Bay, contains about 45 per cent of labradorite in phenocrysts surrounded by a groundmass including both granular and poikilitic hornblende. The hornblende is of the typical basaltic variety, having a maximum extinction of 10° and pleochroic as follows: Z and Y dark red-brown, X very light yellow-brown, absorption $Z > Y > X$. This hornblende is rare in the basic igneous rocks of southeastern Alaska, its place usually being taken by varieties of common hornblende. The rock contains about 10 per cent of magnetite, which crystallized early, in branching and simple octahedral forms. The rock contains a small amount of biotite, which is pleochroic, ranging from almost black to very light yellowish brown.

Specimen 65. Dolerite (diabase), from a dike about 4 miles south of Hadley. A medium to fine grained rock containing zoned plagioclase of composition ranging from Ab_2An_3 to Ab_1An_3. Titaniferous augite occurs both in grains and in irregular masses having an ophitic intergrowth of feldspar. Magnetite inclosing feldspar forms large poikilitic masses.

Specimen 11. Hornblende basalt, from a dike 3½ miles northwest of Hadley. This rock is hypocrystalline porphyritic, having phenocrysts of hornblende, completely altered to serpentine and chlorite, scattered through a groundmass of plagioclase, augite, basaltic hornblende, iron ore, and glass. The augite is in part at least earlier than the feldspar, the basaltic hornblende is in part earlier and in part later than the feldspar. Interstices among the minerals once probably filled with glass are now masses of calcite and chlorite. Many small amygdules have been lined with chlorite and subsequently filled with calcite.

Specimen 386a. Melaphyre (basalt). A fine-grained hypocrystalline rock containing scattered phenocrysts of serpentinized augite and feldspar (Ab_2An_3). The partly glassy groundmass or base is filled with dark-brown needle-shaped crystallites, which extinguish obliquely. Amygdular cavities are filled with calcite.

AGE.

The geologic period in which these basic diabase and basaltic dike rocks were intruded into the metamorphic rocks of Kasaan Peninsula can be determined only by their relations to the other intrusive rocks. These dike rocks intersect the granitic intrusives, the porphyries, and the ore deposits, and also occur along joint planes both in the intrusive and intruded rocks. They are therefore the most recent rocks formed on Kasaan Peninsula and, judging from the occurrence of these rocks at other localities in the Ketchikan district, they are probably of Tertiary age. The basalt dikes crosscut the dikes of diabase and dolerite and are therefore the younger.

GEOLOGIC HISTORY.

The geologic record of events on Kasaan Peninsula begins with the deposition of a series of fragmental rocks, now represented by banded quartzites, graywackes, and conglomerates, and some tuffaceous beds. This series includes narrow beds of limestone which, though no fossils were found in them, are believed to be Devonian. The entire series is much folded and its beds stand nearly vertical, so that its thickness is difficult to determine, but it is believed to be several thousand feet thick.

There is no other geologic record until the early part of the Mesozoic era, but in the meantime these sediments were subjected to intense metamorphism and partial recrystallization due to pressure of overlying strata and to structural changes, which caused the beds to become intricately folded, the direction of the axes of folding being generally northwest.

During early Mesozoic time the rocks of the region were invaded by granitic intrusives. This granitic intrusion was a most important geologic event, as it caused the deposition of the ore bodies. It extended over a long period and produced much fracturing, folding, and metamorphism of the invaded rocks. This intrusion was probably deep seated and the intruded rock solidified far below the surface of that time, as there is no evidence that it extended to the surface. After the granite solidified the pegmatite-aplite dikes were injected from the still fluid portions of the granitic magma. Cracks and fissures were then formed near the contact of the intrusive rocks. These openings, which may have been caused by contractions due to further cooling of the intrusive mass, served as channels for carrying the mineralizing solutions from which the ores were deposited.

The porphyritic dike rocks were also intruded into the sedimentary strata about this time and produced much metamorphism in the adjacent sediments, and locally along the contact rock sulphides were formed, though so far as known less abundantly than along the granitic masses.

A period of active erosion followed the uplift of the Kasaan Peninsula caused by the invading granitic masses, and during this epoch the main valleys, Clarence Straits and Kasaan Bay, which may have been begun at an earlier period, were greatly deepened. This period of erosion continued until the underlying granitic intrusives were exposed and the main features of the present topographic relief were formed. Later the land subsided, these main valleys became salt water channels, and then followed the ice period, which submerged these mountains under a sea of ice. The ice streams advanced from the northwest, carried erosion still farther, and brought with them bowlders and débris foreign to the region, depositing this material on the hilltops and forming bench deposits on the valley slopes. After the retreat of this ice sheet erosion continued to deepen the gulches and remove the deposits left by the glaciers.

The effects of this erosion on the ore deposits, located as they are on the mountain tops and hillsides in rocks little affected by chemical action, such as oxidation, has been extensive and therefore the ore deposits are primary, whereas those in most mineral-bearing regions are secondary.

COPPER ORES.

GENERAL FEATURES.

The copper deposits on Kasaan Peninsula consist of primary ores which show but slight traces of weathering or of concentration by circulating waters. They are similar in occurrence to the ores on Copper Mountain, which have already been described (p. 44).

Four types or ore deposits, defined principally by their mineral composition but also by their mode of occurrence, have been recognized:

1. Contact deposits forming irregular masses along intrusive contacts and consisting of chalcopyrite-magnetite ores and chalcopyrite-pyrrhotite ores associated with amphibole, garnet, feldspar, epidote, and calcite.
2. Disseminated deposits forming irregular, ill-defined masses in gabbro intrusives, and consisting of bornite-chalcopyrite ores intimately associated with the primary minerals of the intrusive rock and secondary epidote and calcite.
3. Shear-zone deposits occupying fissures along shearing planes in the graywackes, consisting of chalcopyrite-pyrite-sphalerite ores associated with a quartz-calcite-barite gangue.
4. Vein deposits occupying fissures in limestones and granitic intrusives and consisting of galena-sphalerite-chalcopyrite ores in a quartz-calcite-barite gangue and auriferous pyrite in quartz veins.

The deposits of the first and third types are the principal copper producers (1908). Deposits of the second type are being developed at several places, and from one mine—the Goodro—shipments of ore taken from deposits of this type have been made. Deposits of the third type have been developed at the Rush & Brown mine and at certain prospects. The vein deposits of the fourth type have been prospected at several points but have not yet been mined.

CONTACT DEPOSITS.

OCCURRENCE.

The term "contact deposit" is here restricted to mineral veins or ore masses that have been formed by contact-metamorphic action and that carry the minerals characteristic of such action. A contact deposit must therefore lie near an intrusive rock, though not necessarily at its contact.

At the time of their intrusion the igneous rock masses or dikes forced their way through the sedimentary rocks, to some extent folding and fracturing them. While they were cooling both the intruded and intrusive rocks naturally shrunk somewhat, and the shrinkage caused cracks and fissures to form near the contacts. These fissures became channels for mineral-bearing solutions, derived, presumably, from great depths, where the temperature was high. On ascending along the contacts, where the temperature was lower, these solutions deposited their mineral content and to some extent replaced the rocks along their course. The contact deposits therefore lie within the contact zone, between the intrusive and intruded rocks, and are believed to have been derived from the same magma that formed the adjacent igneous rocks. Their genesis, however, will be discussed elsewhere (p. 102).

CHARACTER.

The minerals commonly associated with the contact deposits are chalcopyrite, pyrrhotite, pyrite, and magnetite. The gangue minerals are principally garnet and pyroxene, with which are associated variable quantities of epidote, calcite, quartz, amphibole, wollastonite, and feldspar, besides several rarer minerals. These minerals are typical of contact-metamorphic deposits. Mineralogically, these ores differ from the ores of other deposits, especially in the contemporaneous formation of metallic oxides and sulphides, principally of iron, in association with the various lime-silicate minerals named above.

The ore deposits themselves within the contact zone consist of irregular masses ranging in diameter from a few feet to 100 feet or more. Few of them have well-defined limits, most of them merging gradually into barren contact rock. At a few places the ore-bearing contact rock is surrounded by the granitic intrusives; at other places it is surrounded by sedimentary rocks, no surface exposures of the intrusive rock appearing near it. Veins of contact rock carrying ore also cut the intrusive as well as the intruded rocks, though these veins are of little commercial importance.

The copper ore is entirely chalcopyrite and occurs in small masses and grains scattered through the contact rock, and also in the masses of magnetite. Only the parts of the contact rock or magnetite bodies that are sufficiently rich in copper to be profitably mined are regarded as ore.

EFFECT OF INCLOSING ROCK ON ORE FORMATION.

The size of the contact deposits and the width of contact rock at any particular place depend to some extent on the size of the intrusive mass at that place. The largest contact deposits on Kasaan Peninsula are those that have been exploited at the Mamie and Mount Andrew mines, which are near the large intrusive mass that constitutes the southeastern half of the peninsula. Smaller deposits, some of them, however, richer in copper, lie near smaller intrusive masses. These smaller deposits are exploited by the It and the Rush & Brown mines. Still smaller deposits lie near dikes of syenite porphyry and many of them have been prospected, though none have yet afforded ore bodies large enough to be mined profitably.

The general occurrence of the contact deposits at places where limestone is the intruded rock suggests that the lime carbonate helped to effect the precipitation or development of the ores at such points.

DISSEMINATED DEPOSITS.

Irregular disseminated bodies of copper ore occur in an intrusive belt of gabbro that extends along the northeast side of the salt chuck at the head of Kasaan Bay, extending northwestward and averaging about a mile in width. Copper ore has been found at only a few places in this intrusive belt and has been mined only at the Goodro mine.

Where the ore deposits occur the gabbro is partly recrystallized and contains large crystals of biotite and crystals of feldspar having a poikilitic mottling due to partial replacement by biotite. The rock also contains epidote and groups of large crystals of orthoclase, with biotite and epidote and some garnet. The bornite and chalcopyrite ores occur with the secondary minerals last named. It appears that these ore minerals were introduced into the gabbro by the same mineralizing agencies that caused the metasomatic development of the secondary minerals. These agencies may have been directly related to those that produced the contact deposits; and if so, these deposits are only a phase of the contact deposits.

SHEAR-ZONE DEPOSITS.

Ore bodies representing shear-zone deposits occur near the head of Karta Bay, at the Rush & Brown mine and at the Venus prospect. These deposits consist of lenticular veins, from a few inches to a foot or more wide, of massive sulphide minerals, the veins being distributed along shear zones, from 2 to 10 feet wide, in the graywacke country rock.

The deposits contain chalcopyrite, pyrite, and some sphalerite in a gangue of much-altered graywacke and some quartz and calcite.

VEIN DEPOSITS.

Vein deposits that occupy fissures in limestone, from 1 foot to 5 feet wide, have been prospected on Kasaan Mountain. They contain galena, tetrahedrite, some sphalerite, and chalcopyrite, their principal valuable metallic content being lead and silver and some gold. The gangue minerals are quartz, calcite, and barite, but chiefly quartz.

Quartz veins carrying pyrite and some gold and chalcopyrite have been prospected on Grindall Point, at the south end of Kasaan Peninsula. The veins occur in the granite intrusives and measure 6 feet or more in width. These deposits have been exploited by prospect shafts and tunnels, but the ore is of low grade and no great amount of it has been found.

PERSISTENCE OF ORE BODIES.

These various types of ore bodies show different degrees of persistence. The contact deposits are generally small, irregular masses and are no more persistent in depth than they are laterally, but where these masses have been found in a wide contact zone further exploration will probably reveal similar ore masses, both laterally and in depth. The copper-iron sulphide deposits in shear zones in the stratified rocks are more persistent than the contact ore bodies and probably go deeper. The vein deposits in the limestones will also be extensive in depth, but will vary greatly in width, in places narrowing to a mere seam. To judge from like deposits elsewhere, possibly the lead-silver ores will be replaced by copper ores in depth.

MINERALS OF THE DEPOSITS.

The minerals in the ore deposits on Kasaan Peninsula are very similar to those that occur in the Copper Mountain region already described (p. 47). It is not necessary to repeat these descriptions here, but a list of the minerals found in the different types of ore deposits is given below.

Contact deposits.		Disseminated deposits.	Shear-zone deposits.	Vein deposits.
Chalcopyrite.	Garnet.	Chalcopyrite.	Chalcopyrite.	Galena.
Pyrite.	Epidote.	Bornite.	Pyrite.	Tetrahedrite.
Pyrrhotite.	Hornblende.	Chalcocite.	Sphalerite.	Chalcopyrite.
Magnetite.	Diopside.	Pyrite.	Galena.	Sphalerite.
Specularite.	Scapolite.	Native copper.	Quartz.	Pyrite.
Ilvaite.	Wollastonite.	Epidote.	Sericite.	Quartz.
Molybdenite.	Orthoclase.	Amphibole.	Calcite.	Calcite.
Azurite.	Chlorite.	Biotite.	Chlorite.	Siderite.
Limonite.	Quartz.	Calcite.	Amphibole.	Barite.
Malachite.	Calcite.	Quartz.		Chlorite.

In the contact deposits on Kasaan Peninsula the amount of hornblende and feldspar in the contact rock is greater than in the similar deposits on Copper Mountain, for the graywacke, which at most places forms the hanging wall of these deposits, has entered largely into their composition. Tremolite and wollastonite are rare, having been found only where limestone beds occur at the contacts. No zeolite was found. A few specimens of ilvaite with calcite matrix were noted in the contact deposits. (See Pl. XIX.)

Bornite and chalcocite, which occur in the disseminated deposits, were not found in the Copper Mountain area. The mode of occurrence of the minerals in the vein and shear-zone deposits is similar in both districts.

MINING ON KASAAN PENINSULA.

HISTORY.

Copper was first discovered on Kasaan Peninsula by the Russians about 1865. Between 1895 and 1900 most of the mineral locations were made and the mine developments were begun. During the following five years there were more extensive developments and nine plants were installed, aerial tramways were erected, and a smelting plant was built at Hadley. Copper was first produced from these mines in 1905, the year in which the Hadley smelter was completed. Copper production continued, gradually increasing in amount, until the autumn of 1907, when most of the mines ceased operations.

In the summer of 1908 the Hadley smelter was again in use, and some of the mines renewed operations, but for a short period only. From 1909 to 1913 the smelter was idle, though certain of the mines continued operations, shipping the ore to the Tyee and Tacoma smelters.

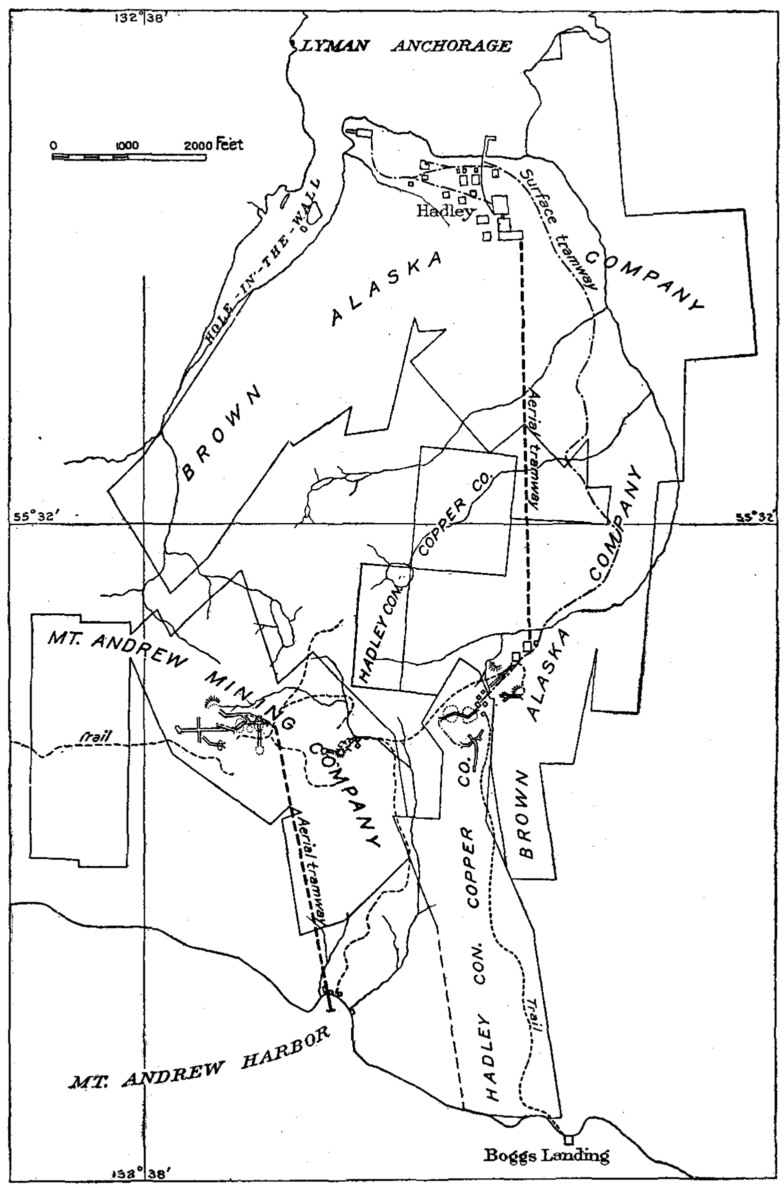


FIGURE 7.—Map showing properties of the Brown Alaska Co., Hadley Consolidated Copper Co., and Mount Andrew Mining Co. (1908).

MINES SOUTH OF HADLEY.

GENERAL FEATURES.

Three of the principal mines on Kasaan Peninsula are near the summit of the mountain ridge about 1½ miles south of Hadley, at altitudes of 700 to 1,400 feet. These are the Mamie, Stevenstown, and Mount Andrew mines, and their relative positions and the extent of the mining property belonging to the companies owning them in 1908 are indicated on the sketch map forming figure 7. The ore bodies are included in the contact rock and are associated with large masses of magnetite. They occur along a mineral zone between the diorite intrusive mass and a narrow belt of limestone, which is traceable for about 2 miles from the east side of Mamie Creek westward to Kasaan Bay. This zone ranges in width from 100 to 300 feet, though, because of its flat dip and its conformity with the contour of the mountain slope, it appears locally to be much wider. The ore bodies are locally concentrations of chalcopyrite, generally in masses of magnetite. Though the ore masses discovered are limited both laterally and in depth, continued exploration has generally revealed new ore bodies both in depth and laterally.

The ores from these mines are of low grade, the copper content being almost entirely in the form of chalcopyrite. Besides copper they contain from $1 to $2 in gold per ton. In composition they average about 15 to 20 per cent of silica, 30 to 40 per cent of iron, 4 to 6 per per cent of sulphur, and 10 to 15 per cent of aluminum.

MAMIE MINE.

Situation and development.—The Mamie mine, owned by the Brown Alaska Co., is 1¼ miles south of Hadley, at an elevation of 700 feet, in the central part of Kasaan Peninsula. (See Pl. XX and fig. 7.) The mine workings are connected with the smelter at Hadley by an aerial tram 5,500 feet in length and with the beach by a horse tram 7,700 feet in length. The horse tram is used for transporting supplies. Mine developments in a large way were not begun until 1904. During that year the ore bodies were explored by numerous open cuts, tunnels, and diamond-drill holes. In the following year mining was begun from the open pits and new ore bodies were developed by tunnels and shafts. At the close of 1905 considerable ore was delivered to the smelter, and throughout 1906 the production was large. In 1907 diamond-drill investigations were advanced, new ore bodies were located at greater depth, and the ore

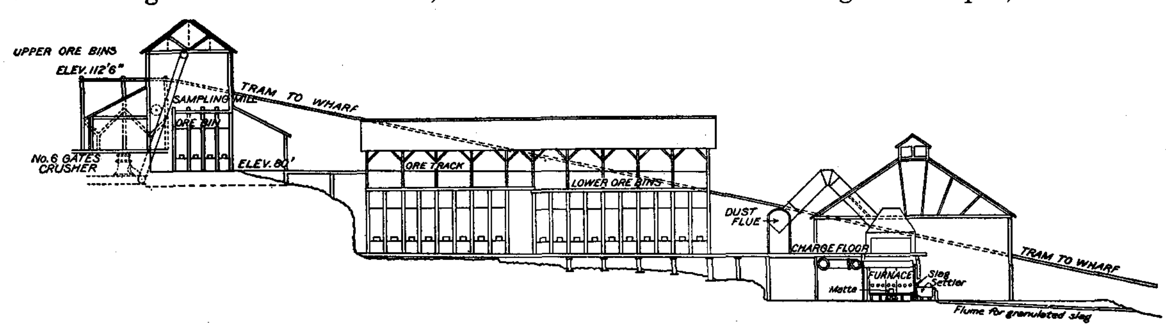


FIGURE 8.—Section of Hadley smelter.

production continued with little interruption until late in September. In October all operations were suspended. The total developments up to 1908 consist of 5,000 feet of tunneling, drifting, and crosscutting and about the same amount of diamond-drill prospecting. The smelter or reduction plant at Hadley consists of a blast furnace of 350 tons daily capacity, a sampling mill, coal and coke bins, ore bunkers of 10,000 tons capacity, boiler house, engine house, electric-light plant, and other conveniences. The ores from the Mamie and Stevenstown mines first go through the samplers, next to the ore bunkers by gravity, and thence by gravity to the furnace. The slag from the furnace is granulated and carried by water to the beach. A cable tramway extends from the wharf to bins above the sampling mill, which have been built to receive custom ore. The plant is so arranged that its daily capacity may be doubled if necessary. Smelting operations began December 5, 1905, and in 1906 the furnace was in blast about 20 days each month. In September, 1907, this plant was closed. (See Pl. XXI, *B*, and fig. 8.)

Early in the summer of 1908 the Mamie and Stevenstown mines were consolidated under one management, which obtained a lease of the smelter. The underground workings at the Mamie mine were pumped out and repaired and mining developments were begun. The smelter was reconstructed to treat a larger quantity of ore and was put into operation early in September. The mines and smelter were operated until the first of November, the smelter treating an average of 360 tons daily. The lack of siliceous ores, however, necessitated the suspension of operations at both the mine and smelter. The Mamie mine and Hadley smelter have both been idle since 1908 (1913).

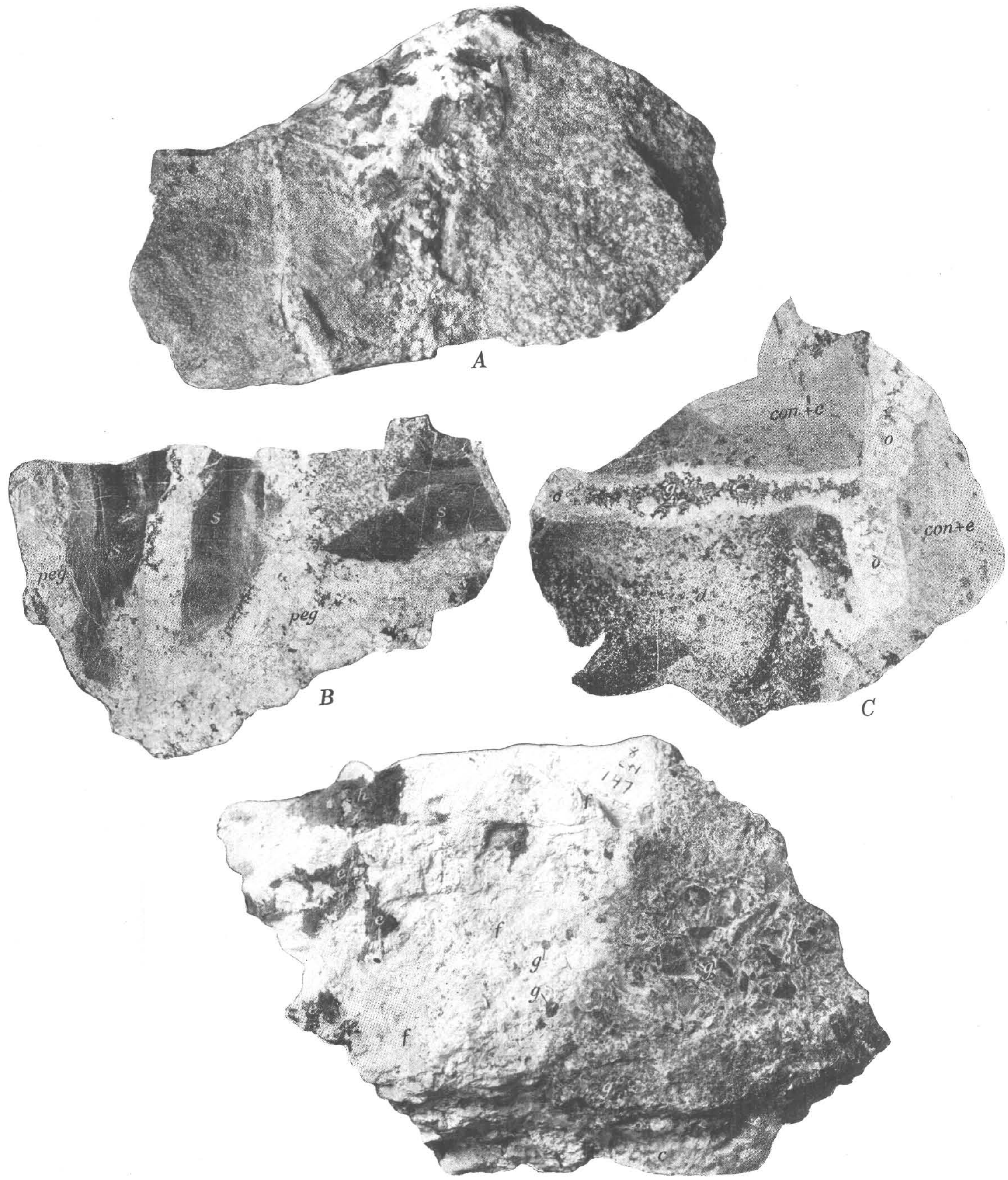
PLATE XVIII.

A. Specimen from Rush & Brown mine, showing contact of diorite with graywacke and development of pegmatite along contact.

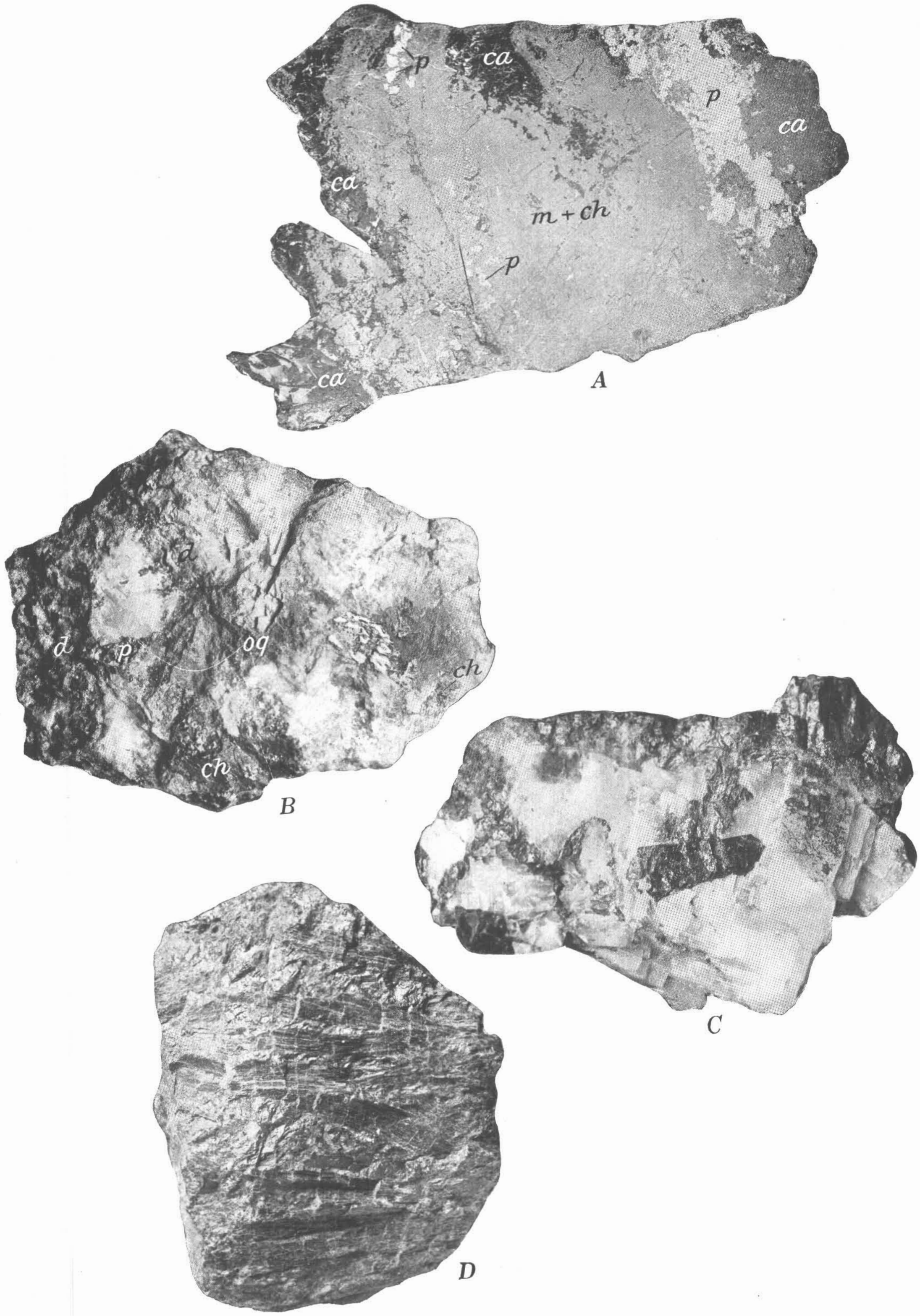
B. Pegmatite phase of diorite, with inclusions of schist; *peg*, pegmatite; *s*, schist.

C. Specimen from Mount Andrew mine, showing orthoclase veinlet cutting altered diorite and entering contact rock; *con*, Contact; *e*, epidote; *d*, altered diorite; *g*, garnet; *o*, orthoclase veinlet.

D. Feldspar dike with epidote cutting contact rock; *c*, calcite; *e*, epidote; *f*, feldspar; *g*, garnet; *h*, fibrous hornblende.



ROCKS FROM MINES ON KASAAN PENINSULA.



ORES AND MINERALS FROM MINES ON KASAAN PENINSULA.

PLATE XIX.

A. Ore from Mount Andrew mine, showing association of magnetite, pyrite, and chalcopyrite in contact rock; *ca*, calcite amphibole rock; $m + ch$, magnetite and chalcopyrite; *p*, pyrite.

B. Ore from It mine, showing altered diorite, chalcopyrite, and pyrite in orthoclase quartz contact rock· *d*, diorite; *ch*, chalcopyrite; *p*, pyrite; *oq*, orthoclase and quartz.

C. Ilvaite from Mount Andrew mine.

D. Hornblende with chalcopyrite ore from Stevenstown mine.

Ore bodies.—The ore bodies at the Mamie mine are contact deposits included in a zone 400 feet wide lying between a diorite intrusive mass and a limestone. Within this zone the masses of valuable copper ore are limited either by such a decrease in the copper content of the inclosing rock as to prohibit profitable extraction or by fault planes. Garnet, pyroxene, epidote, hornblende, and magnetite compose the contact rock. Chalcopyrite occurs in small quantities throughout the rock. The ore bodies, or the portions of the contact rock where the copper is sufficiently concentrated to make ore, are irregular masses ranging from 50 to 100 feet in length and from 10 to 40 feet in width, the major axis striking northward. Nine such ore masses are exposed in the mine workings. Some of them are included entirely in masses of magnetite, thus making basic ore; others occur in the garnet-epidote gangue rock, making a siliceous ore. Veinlets of calcite and some of quartz intersect the ore masses, indicating a later period of mineral deposition, though the main ore bodies are believed to have been deposited contemporaneously with the inclosing contact rock. (See Pl. XVIII, *B* and *D*.)

STEVENSTOWN MINE.

Situation and development.—The Stevenstown mine (Pl. XXI, *C*), owned by the Hadley Consolidated Copper Co., is just above and southwest of the Mamie mine, at an elevation of 1,000 feet. (See fig. 7.) From the mine a surface tram 700 feet long connects with the aerial tram at the Mamie mine, over which the ore is transported to the smelter at Hadley. A trail also leads from the mine down the south side of the peninsula to Boggs Landing, on Kasaan Bay, a distance of 1 mile. In 1908 the mine was developed by three "glory holes" or open pits, connected by raises with a 550-foot tunnel that penetrates the crest of the mountain. Actual mining was begun in June, 1905, before which time prospecting had been carried on, and in September, 1905, ore shipments to the Hadley smelter began. A large amount of ore was produced during 1906 and until the first of July, 1907, when mining was suspended. In 1908 operations were renewed and additional output was made and sent to the smelter at Hadley. In the autumn of that year, however, the mine was closed.

Ore bodies.—The ore bodies on the Stevenstown property correspond both mineralogically and genetically with those at the Mamie mine. They occupy a relatively flat position on the crest of the mountain ridge and are apparently underlain by the monzonite intrusive which forms the footwall of the mineral belt and which is exposed throughout the tunnel that penetrates the mountain top. The hanging wall as well as a large portion of the ore bodies on this property have been removed by erosion and the contact zone is only 20 to 40 feet in width instead of 200 to 400 feet, the width on the Mamie property just below. Strata of limestone and of greenstone tuff lie northeast of the ore bodies and continue westward toward the Mount Andrew mine, forming the hanging wall of the mineral zone.

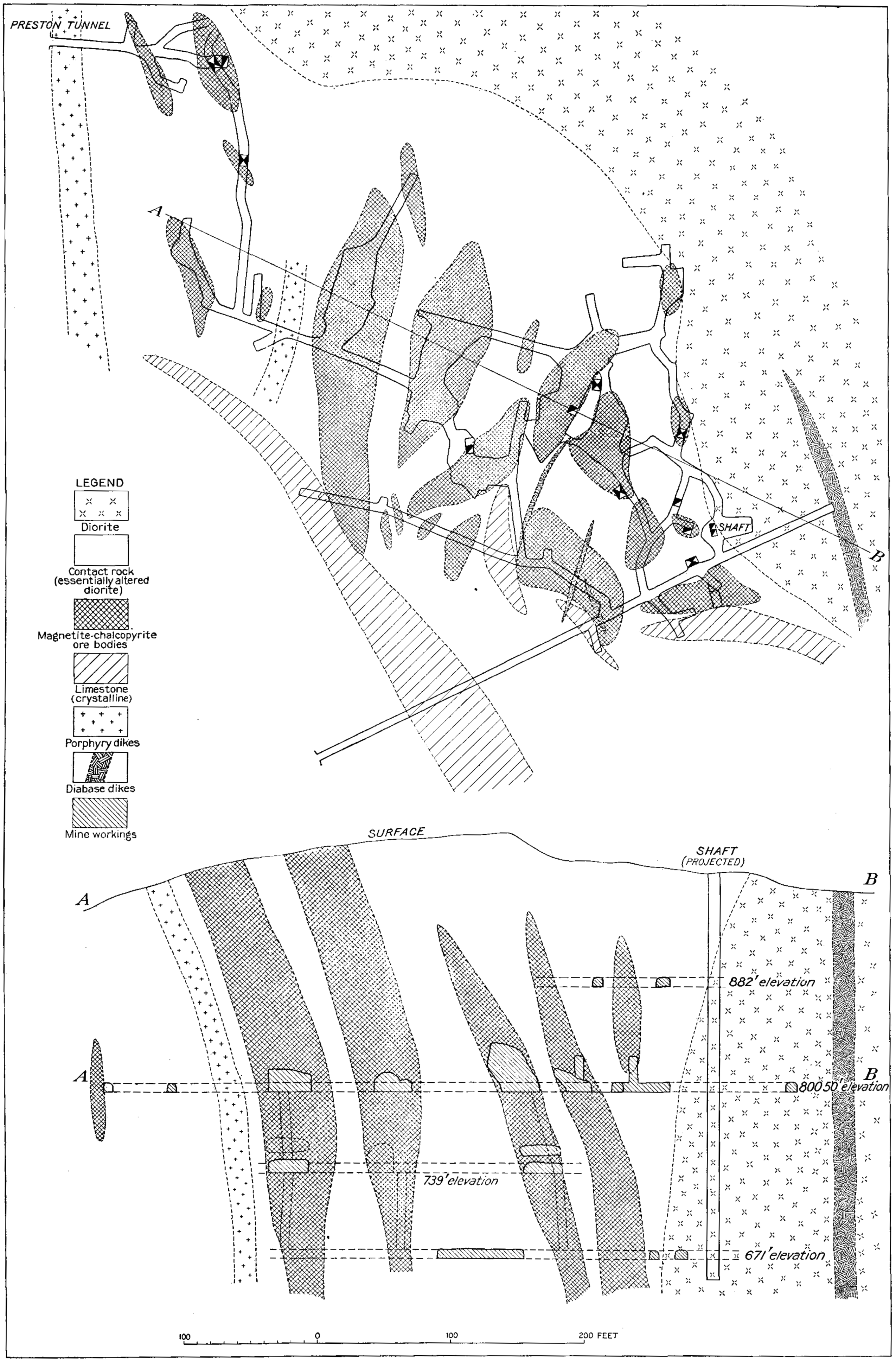
The mine workings are all surface pits connected by raises with the main tunnel and have developed several relatively flat-lying ore masses. These masses are included within an area measuring 350 by 200 feet, the pits being 20 to 40 feet deep. The central portion of this area is traversed from north to south by a 40-foot felsite dike, which is of later intrusion than the syenite and crosscuts the ore body. Smaller dikes of diabase and basalt, 1 foot to 5 feet in width, crosscut the ore bodies and country rock at several points in these mine workings.

The ore is chiefly magnetite, chalcopyrite, and pyrite associated with hornblende and calcite, all included in a more or less banded garnet-epidote gangue. (See Pl. XIX, *D*.)

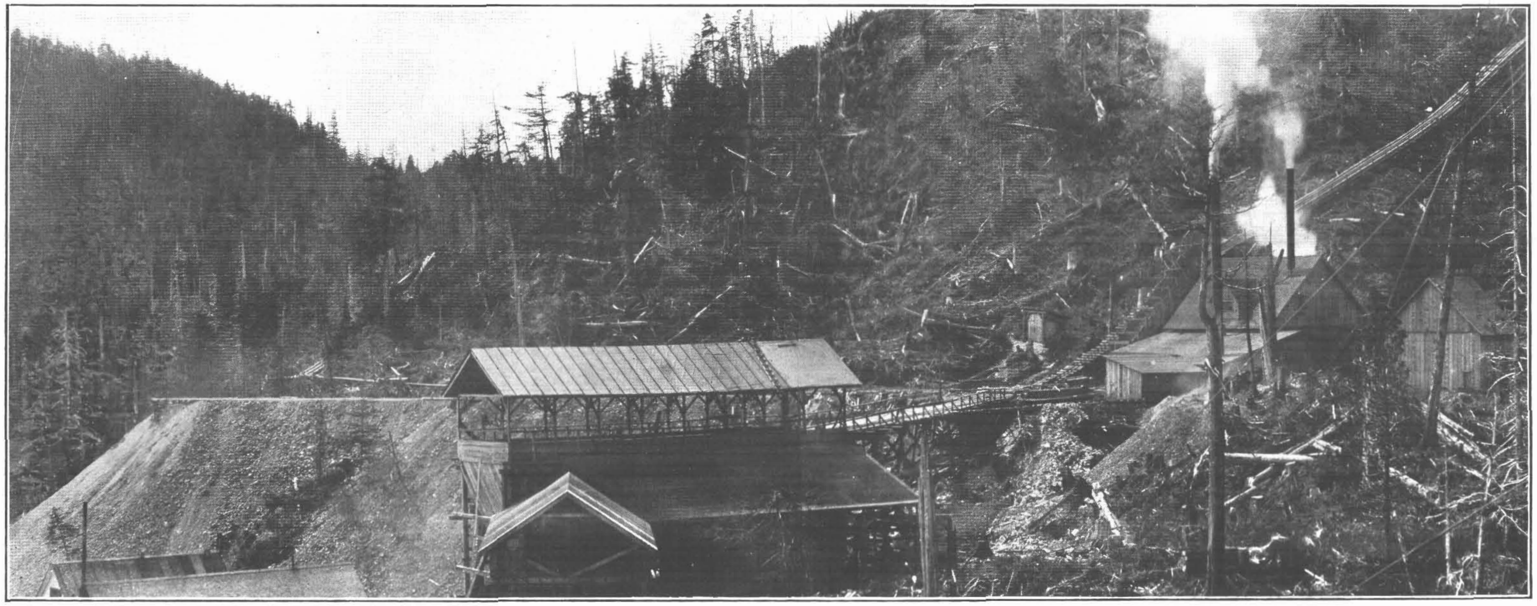
Surface oxidation has produced considerable limonite and some malachite and azurite; small particles of native copper also occur along slipping planes, though these secondary minerals are relatively unimportant.

MOUNT ANDREW MINE.

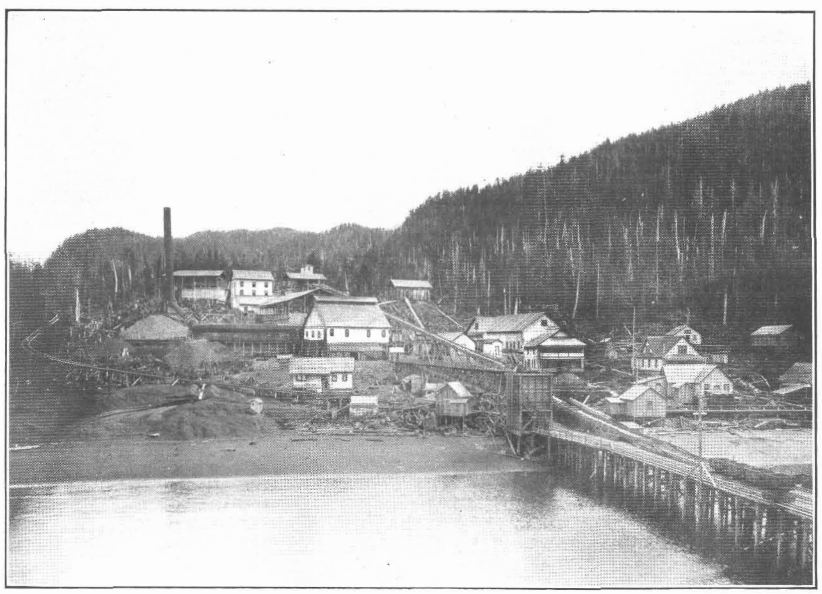
Situation and development.—The Mount Andrew mine workings are three-fourths of a mile from Mount Andrew landing, on the southwest side of Kasaan Peninsula, and one-half mile west of the Stevenstown mine, at an elevation of 1,400 feet. A cable tramway 3,600 feet long leads from the mine to the ore bunkers and wharf at Mount Andrew landing.



PLAN AND SECTION OF WORKINGS OF MAMIE MINE IN 1908.



A. SURFACE WORKINGS OF MAMIE MINE IN 1908, SHOWING TRAMWAY TO STEVENSTOWN MINE.



B. HADLEY SMELTER.

C. WORKINGS OF STEVENSTOWN MINE IN 1908.

This mine is developed (1908) principally by a tunnel 620 feet long, which undercuts the ore bodies at depths of 60 to 100 feet or more. From this tunnel several hundred feet of drifts and crosscuts have been driven, and upraises have been carried through the ore bodies to the surface. The ore is mined from large underground stopes and from surface pits or glory holes and is delivered through chutes at tunnel level to the ore bunkers at the head of the aerial tram and thence carried to the wharf, where it is loaded for shipment. Developments in a large way were not begun until late in 1905, and during 1906 the aerial tram was erected, the wharf built, the compressor plant installed, and considerable ore developed. The first ore

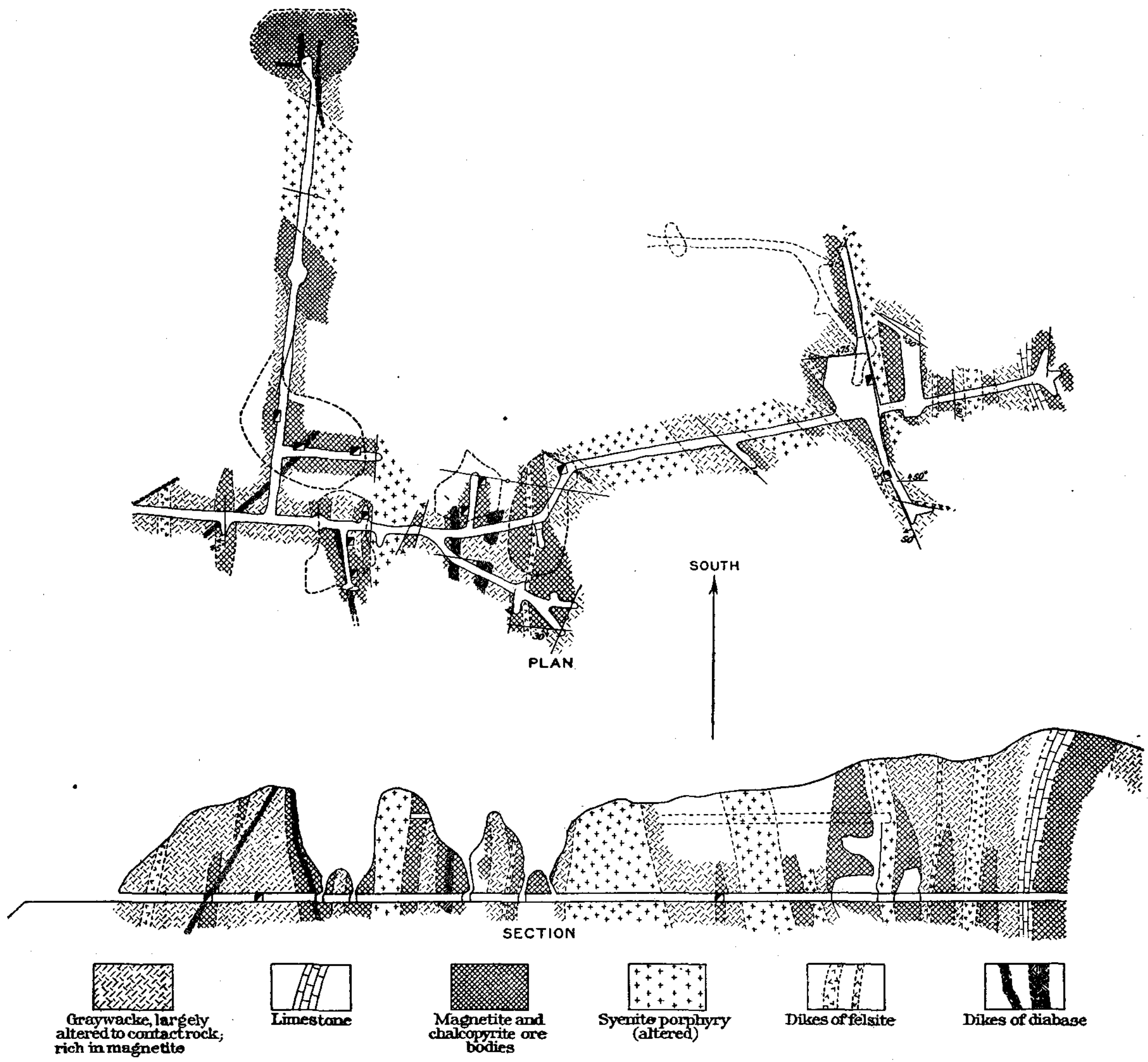


FIGURE 9.—Plan and section of workings of the Mount Andrew mine (1908). This illustration is diagrammatis and generalized.

shipments were made in October, 1906, and production continued until October, 1907, when operations were suspended.

In 1908 the mine was not operated. In 1909 operations were renewed under the management of the proprietary corporation, the Mount Andrew Iron & Copper Co., and from March until late in the autumn a steady output was maintained. During the winter of 1909 developments were continued and additional ore reserves were opened. Shipments began again early in the spring of 1910 and the usual annual production was recorded for that year. The most noteworthy development work undertaken in 1910 was that on the new 1,600-foot adit tunnel, which starts at the old camp and is projected to undercut the ore bodies 300 feet below the present working levels. (See fig. 9.) In 1911 the mine continued producing, though its output was somewhat less than in former years.

Ore bodies.—The ore deposits on this property are included in the same mineral belt as those at the adjacent Mamie and Stevenstown mines, with which they are in every way comparable. Six ore bodies, consisting of irregular masses of magnetite-chalcopyrite associated with the garnet-epidote contact rock, have been developed and have been mined to a considerable extent. These bodies of ore are 10 to 50 feet wide, 40 to 80 feet long, 100 feet or more in depth, and have a general northerly strike and pitch. They are separated by barren areas of contact rock and dikes 20 to 60 feet wide of altered syenite porphyry. (See Pl. XXII, *A*, and fig. 9.) The mine workings consist essentially of surface pits which are undercut by a crosscut tunnel running east and west. This tunnel, with connecting drifts and raises, includes 2,200 feet of underground developments. Numerous gouge seams and slickensides, indicating faulting, were observed in the mine workings, and some of the ore bodies were laterally displaced 1 foot to 6 feet. Dikes of diabase and felsite, from 2 to 12 feet wide, crosscut the ore bodies and country rock in various directions and were evidently intruded after the ore deposits had been formed. (See Pls. XVIII, *C*, and XIX, *A* and *C*.)

At other points on Mount Andrew large masses of the magnetite carrying an amount of copper insufficient to make a copper ore have been formed. These deposits, though not valuable for their content of copper alone, may sometime be a source of iron.

MINES AND PROSPECTS NEAR KASAAN BAY.

TYPES OF DEPOSITS

Along the northeast shore of Kasaan Bay there are a number of copper prospects and one producing mine. Two types of contact deposits were recognized. One type, at the contacts of diorite masses, is represented by the It mine and the Alarm, Haida, and Copper Center prospects; the other type occurs at the contacts of dikes of syenite porphyry and diorite, and is represented by the Uncle Sam, Ouray, and Copper Queen prospects. The deposits of the first type are concentrations of chalcopyrite ore in the contact rock between the diorite and either the limestone or the graywacke. The bodies of minable ore are from a few feet to 25 feet or more in thickness and are generally more siliceous and richer in copper than those at the Mamie and Mount Andrew mines. The ore bodies along the syenite porphyry dikes contain rich ore here and there, but have added little to the copper production of the peninsula.

IT MINE.

Situation and development.—The It Mining Co. was organized early in 1908 and acquired what were formerly known as the Taylor prospect and the Eagle's Nest group. These prospects are 4 miles northwest of Kasaan, 4,000 feet from the shore line, at an elevation of 400 feet. They were developed to some extent in 1907 by the Sea Island Copper Mining Co., but reverted to the original owners, who sold them to the It Mining Co. Development work was begun by this company in May, 1908, and by the end of September a surface tramway 1 mile long and a wharf were completed, and in October of that year ore shipments were begun. In 1909 the mine was a steady producer and development work was advanced. A compressor plant was established near the wharf and a hoisting engine was installed at the mine. From the short adit level a shaft 50 feet deep was sunk and about 250 feet of development was done at this new level. In 1910 two other levels at depths of 100 and 150 feet were driven, and the ore production was maintained as in former years. Some prospecting was done by diamond drilling. In 1911 a 1,400-foot tunnel was begun, which is projected to undercut the ore deposits at a depth of 500 feet.

The ore from this mine is siliceous and contains little or no magnetite. The gangue is sorted by hand, the product being thus made richer before shipment. (See Pl. XIX, *B*.)

Ore bodies.—The ore bodies are contact deposits which lie on both sides of a diorite intrusive mass. (See Pl. XIX.) The contact zone here is widest on the northeast side of the diorite, where the principal ore bodies are found, though developments on the southwest side have also revealed small masses of ore. The intruded rocks are limestone and graywacke and have been much altered by infiltration of minerals from the contact zone.

The minable ore bodies consist of chalcopyrite, pyrite (often in large octahedral crystals), garnet, epidote, and some hematite. They are from a few feet to many feet in dimensions. Several such bodies have been found and mined and exploration, both in depth as well as laterally, continues to expose masses of ore.

UNCLE SAM MINE.

Situation and development.—The Uncle Sam mine, originally called the White Eagle group, lies 3 miles northwest of Mount Andrew landing and one-half mile from Kasaan, on the south slope of Kasaan Peninsula. (See fig. 10, p. 96.) The mine workings are 430 to 550 feet in elevation and less than half a mile from the beach. Mining operations have been advanced on this property at intervals since its discovery in 1899, and in 1901 an aerial tram, ore bunkers, and a wharf were built. Early in 1906 a shipment of ore was made, but no further work was done until March, 1907. At that time operations were renewed, continuing until July, when another ore shipment was made. The mine is developed (1908) by a tunnel and drifts, amounting to about 800 feet in length, and by open pits exposing the ore body on the surface above the tunnel. From this working tunnel a surface tram 1,150 feet long conveys the ore to the wharf. This mine has now (1912) been closed since the autumn of 1907.

Ore body.—The ore body exposed in the tunnel is an irregular lens of chalcopyrite-pyrite ore 6 to 8 feet in width, striking north and pitching about 45° N. It is cut off to the north by an east-west fault dipping 80° N., which shows but a small amount of gouge. At the open cut above the tunnel similar masses of ore are exposed, but no large ore bodies have been discovered. Garnet, epidote, magnetite, and calcite occur as gangue minerals and in many places form small geodes. The chalcopyrite ore contained in this gangue rock is irregularly distributed in small masses and not along well-defined lines. The country rock is made up of strata of chloritized and epidotized greenstone tuff, which are underlain by the intrusive syenite and are cut cross by small dikes of diabase of later origin than the ore bodies.

COPPER QUEEN GROUP.

The Copper Queen group of claims, which represents the first copper locations on Prince of Wales Island, lies about one-half mile southeast of Kasaan. In 1898 these claims were sold to the Kasaan Bay Mining Co., which made additional locations. Small operations were in progress from 1899 until 1902, and 500 feet of tunneling was done, besides surface excavations. Since 1903 the property has been idle.

The principal ore deposit is exposed along the side of a gulch at a point 300 feet in elevation. It consists of an irregular mass of chalcopyrite ore accompanied by pyrite and magnetite in a garnet-epidote gangue, at the contact of an altered intrusive syenite with the greenstone tuff. Below these exposures a crosscut tunnel 400 feet in length has been driven in the altered syenite, but has failed to reveal any ore.

Other mineral exposures occur on these claims at points close to tidewater and have been prospected by shafts and open cuts, but so far no important deposits have been discovered. Practically no work has been done on this property for several years (1912).

POOR MAN'S GROUP.

The Poor Man's group of two claims is 2 miles northwest of Kasaan. In 1908 the mine workings were connected with deep water by a surface tramway and wharf having a total length of about 2,000 feet. The principal developments are at the head of the tramway and consist of a tunnel, driven 90 feet in a southwesterly direction, which crosscuts a 40-foot body of magnetite ore and 30 feet of garnet-epidote contact rock, and at its face enters a wide dike of red syenite for 20 feet. At a point 80 feet from the mouth of the tunnel is a vertical shaft extending 30

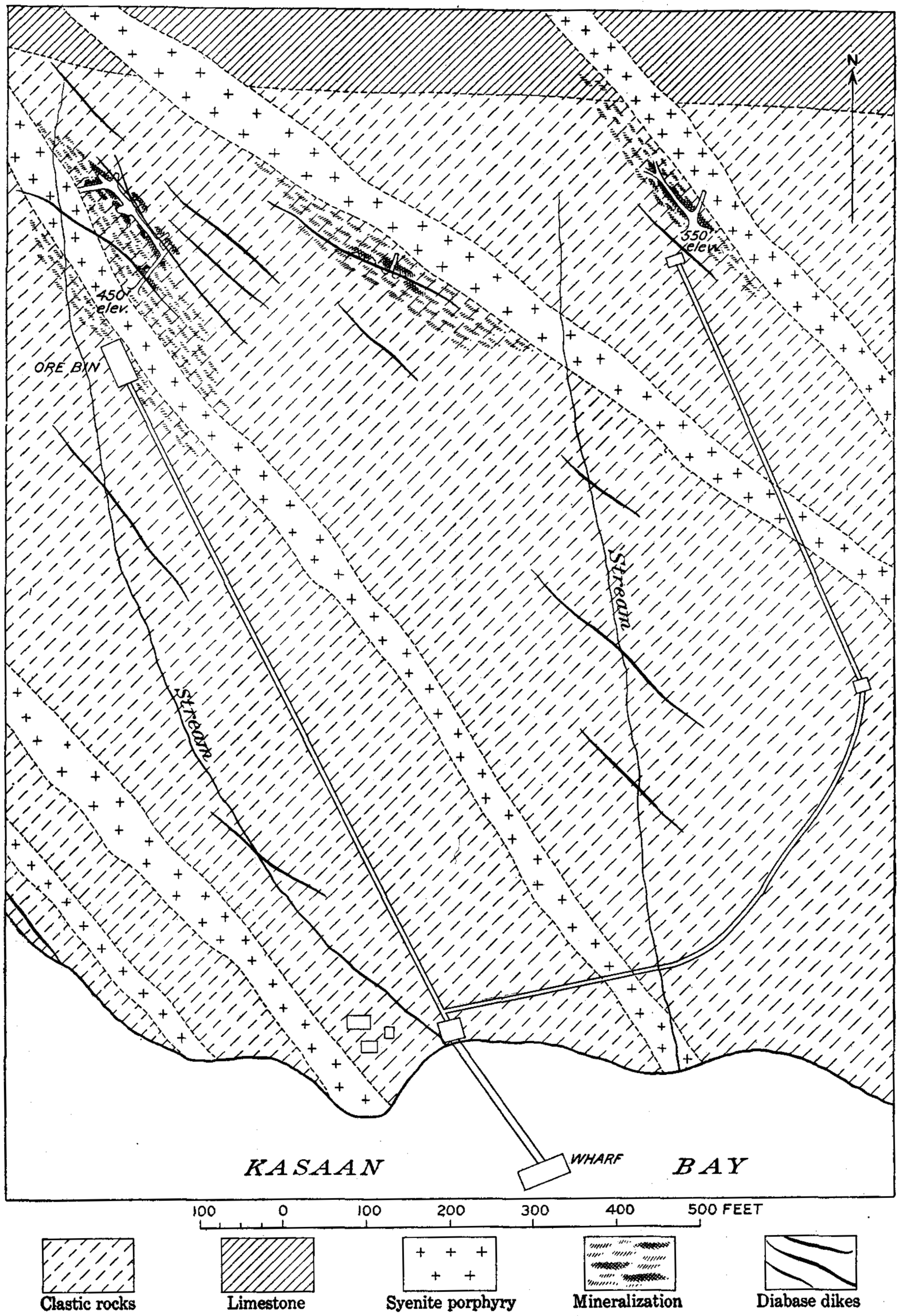


FIGURE 10.—Plan of workings of the Uncle Sam mine (1908).

feet to the surface and 60 feet in depth. This body of magnetite is exposed on the surface above the tunnel, and similar masses have been prospected by short tunnels and cuts and shafts at points along the tramway and on adjoining properties. Associated with the magnetite are large amounts of calcite and hornblende and some pyrite, chalcopyrite, garnet, and epidote. Although the magnetite deposit itself is extensive, the chalcopyrite ore occurs only in isolated pockets or narrow veinlets and is not disseminated throughout the magnetite in sufficient amounts to make a copper ore of the entire body. It is noteworthy, however, that these ore bodies may be of value for their iron content. Minor displacements, due to faulting on slipping planes, and dikes of diabase and felsite crosscutting the deposits were noted.

BROWN & METZDORF PROSPECT.

The Brown & Metzdorf prospect is one-half mile from Kasaan Bay, at an elevation of 310 feet. The ore body is a mineralized mass of garnet rock carrying chalcopyrite and pyrite. It is exposed for a width of 10 feet, showing a banded structure, and evidently replaced the bedded quartzite and greenstone tuff country rock. A wide belt of limestone is exposed in bluffs along the trail just below this prospect.

PEACOCK AND TACOMA CLAIMS.

The Peacock and Tacoma claims are about 3 miles southeast of Kasaan. The Tacoma claim extends to the beach, where open cuts have been made on ore exposures that are covered at high tide. The ore is confined to a garnet-epidote rock and occurs in irregular patches or finely disseminated particles. In the cuts on the beach a small amount of ore is exposed, and above it, at an elevation of 50 feet, a tunnel 60 feet long (1908) enters the hill in a northeast direction. This tunnel crosscuts a wide belt of garnet-epidote rock containing some chalcopyrite. Other open cuts expose small amounts of ore at several places, but no large ore masses have been developed.

The Peacock claims adjoin the Tacoma claim on the north and extend to the center of the peninsula. At 600 feet from the beach and 120 feet above tide a tunnel 45 feet long exposes a belt of garnet-epidote contact rock containing magnetite and a small amount of chalcopyrite. Still higher, at 325 feet, a second tunnel 30 feet long, following the contact of a diabase dike, exposes a smilar mineral-bearing rock. Here also dikes of felsite and basalt occur, and slipping planes displace the mineral body in various directions. The amount of development on these properties has not been sufficient to disclose ore bodies large enough to justify mining, but systematic prospecting may open up deposits of value.

HOLE IN THE WALL PROSPECTS.

The small cove known as Hole in the Wall lies on the north side of the harbor at Hadley, and along its shores and west of it a number of claims have been located, among them (in 1908) the Plumley group and the Eureka, Sunrise, Pennsylvania, Venus, and Pelaska claims. On the Hilma claim of the Plumley group, at a point one-half mile northwest of the head of the cove and 310 feet in elevation, a tunnel 25 feet in length has been driven along the contact of an altered limestone belt with a dioritic batholith, in which small masses of chalcopyrite are exposed in a garnet-epidote-calcite contact rock. On the Eureka claim, at tidewater, similar contact deposits are being developed and are reported to be of considerable extent. The Sunrise claims, three in all, are west of the Hole in the Wall, and on these claims at points along a gulch small ore masses replace limestone beds at or near their contact with granodiorite. At an elevation of 1,050 feet this contact aureole is 25 feet wide and contains considerable magnetite and chalcopyrite ore, which shows much surface alteration. On the south slope of the hill, at an elevation of 950 feet, is an open cut exposing a highly crystalline marble, slightly banded, striking N. 65° E. and dipping 60° NW. This marble overlies the contact rock, which carries small amounts of the copper ore. On the Pennsylvania claims, southeast of the Sunrise claims, an open cut following a felsite dike at an elevation of 850 feet exposes a small vein 2 to 3 feet wide consisting of pyrite with small amounts of chalcopyrite. The prospects on the Venus claims show contact deposits similar to those exposed on the Sunrise claims to the north and are apparently along the same intrusive contact. The Pelaska claim, extending from the head of the cove westward, has been developed by a tunnel over 100 feet in length following a belt of altered limestone intruded by a diabase dike, along which occurs garnet-epidote contact rock carrying some chalcopyrite. This deposit is interesting geologically, but the amount of ore exposed is small.

MINES AND PROSPECTS AT THE HEAD OF KASAAN BAY.

LOCATION.

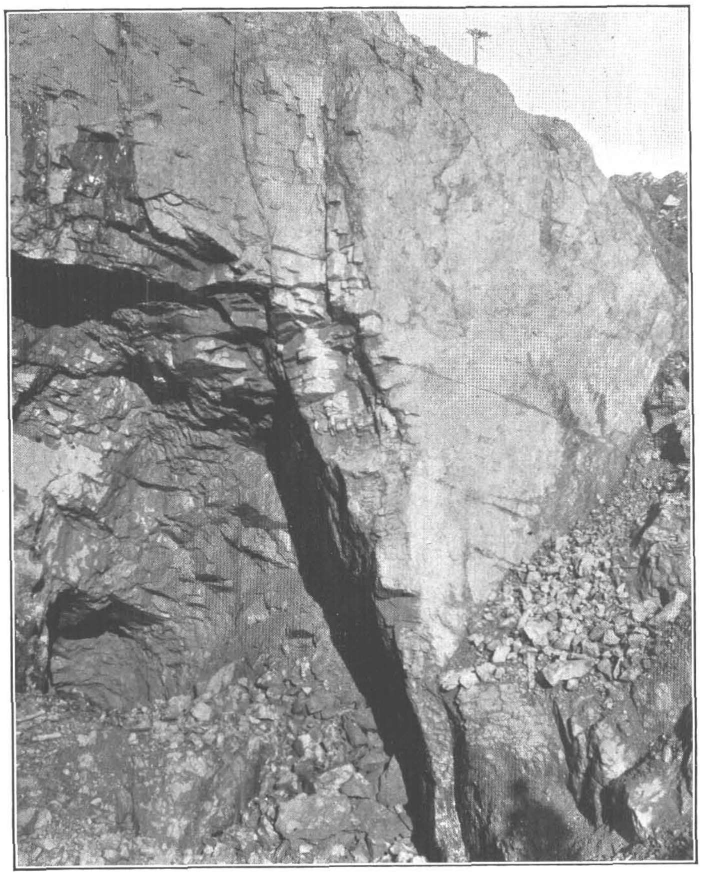
The head of Kasaan Bay includes the entire northwest extension of Kasaan Bay. It is a relatively shallow embayment 3 miles in width, including a number of low wooded islands and shoals, and affording several good anchorages. The adjacent land area is low and is occupied by a "salt chuck" 2 miles in length and by three small lakes. To the southwest is a mountain range including Granite Mountain and other rounded summits less than 4,000 feet in elevation, and to the northeast is a low ridge of hills forming the divide between Kasaan and Thorne bays. The principal mines in the immediate vicinity are the Rush & Brown mine and the Venus group to the northwest and the Goodro claims to the northeast. In 1901, when A. H. Brooks visited this section, none of these properties had been located, and not until 1904 were the copper-bearing ore bodies discovered.

The area is occupied principally by stratified rocks ranging from a fine tuff to a coarse conglomerate, and in places showing a development of large hornblende crystals. These bedded rocks are invaded by granodiorite masses, and dike rocks of various composition intrude both the granodiorite and the bedded rocks. The copper ore occurs (1) at the contacts of the granodiorite with greenstone tuff, conglomerate, and limestone, as at the Rush & Brown mine; (2) along shear zones in the greenstone tuffs and conglomerates, as at the Venus group and Rush & Brown mine; and (3) in small masses and disseminated particles scattered irregularly through an altered basic diorite, as at the Goodro claims.

RUSH & BROWN MINE.

Situation and development.—The Rush & Brown property includes (1908) eight claims extending from the "salt chuck" northwestward, the principal mine workings being located on the Iron Cliff claim, at an elevation of 300 feet, about 2 miles from the wharf at the head of the bay. (See fig. 11.) In 1904 this property was prospected by long trenches and open cuts, and a shaft 25 feet deep was sunk on the ore body. In 1905 it was leased by the Alaska Copper Co. and a new shaft was started 120 feet south of the old shaft and sunk to a depth of 84 feet. From the bottom of this shaft the principal ore body, the magnetite deposit, was developed by drifts and crosscuts and a drift was extended to a second ore body, the sulphide deposit, 160 feet farther northeast. In 1907 the shaft was sunk an additional 93 feet and another level was started. The ore from the mines is transported by a gravity tram to ore bunkers one-fourth mile below the mine and thence by a railroad 2¾ miles long to the wharf at the head of the bay, where ore bunkers of 2,000 tons capacity have been built. During 1906 ore was shipped to the smelter at Coppermount, and in 1907 shipments were made to the Tyee smelter at Ladysmith, British Columbia. The mine was practically idle during 1909–10. In 1911 work was again renewed and since then shipments of ore have been continued.

Ore bodies.—In 1908 two ore bodies had been developed at the Rush & Brown mine. One is a contact-metamorphic deposit consisting of a copper-bearing magnetite body, developed to a length of 100 feet and a width of 30 feet, in the contact-rock gangue lying between diorite and an altered graywacke, the line of contact striking nearly east and west. The other deposit, 160 feet to the north, occupies a shear zone in the greenstone tuff and conglomerate beds and is a sulphide body composed of chalcopyrite and pyrite in a gangue of altered graywacke and quartz and calcite. It is developed to a width of 4 to 14 feet and in 1908 had been followed for a length of 85 feet. The mine management in 1913 reported that the sulphide ore body on the second level was cut off by a fault but was picked up again and explored for a distance



A. PORPHYRY DIKE CUTTING ORE BODY NO. 4, MOUNT ANDREW MINE.

B. ENTRANCE TO SLOPE AND SURFACE CAPPING OF ORE BODY AT RUSH & BROWN MINE.

Photograph taken in 1908.

of 170 feet beyond the fault. The strike of this sulphide deposit is northeastward and its dip is 60° SE., toward the larger deposit. Further exploration will doubtless disclose other ore bodies of the same types. (See Pls. XVIII, *A*, and XXII, *B*.)

GOODRO MINE.

The Goodro mine, also known as the Joker group, is half a mile from the head of the salt chuck entering Karta Bay. The surrounding area is relatively low, the claim being located on a knoll about 400 feet in elevation. The copper deposit at this mine consists of disseminated sulphide ores in a gabbro intrusive belt, which is shown on the geologic map (Pl. XV). At the time of the writer's visit this deposit had been developed by surface pits, an open cut 70 feet long, and a tunnel 125 feet long, which crosscuts the deposit 90 feet below the surface and 90 feet from its mouth. In 1909 a wharf, ore bins, and 3,850 feet of tram (in part gravity and in part horse tram) were constructed, and the shipment of ore was begun. The ore was lightered out of the salt chuck on barges at high tide and loaded on vessels lying at the head of Kasaan Bay. In 1910, after the winter shutdown, operations were again resumed. A winze 100 feet deep was sunk from the main tunnel level, and from its bottom drifts were extended to the east and west 150 feet in length. The winze is said to have been sunk in ore for 45 feet. At the lowest level 14 feet of ore, consisting of disseminated chalcopyrite and bornite in the gabbro, is said to have been crosscut. In 1911 only assessment work is reported to have been done on this property.

The ore deposit at this mine is of special interest because bornite is the dominant metalliferous mineral, and it is the only locality in southeastern Alaska where bornite has been found in quantity. The ore occurs in small masses and disseminated particles associated with epidote, feldspar, and biotite, minerals that largely replace the inclosing gabbro. Native copper, chalcocite, chalcopyrite, and small amounts of gold are also associated with the bornite. The mineralization of the gabbro with bornite is exposed across a width of 60 feet and for a length of 100 feet or more. Other smaller deposits of bornite in the gabbro were noted on adjacent properties.

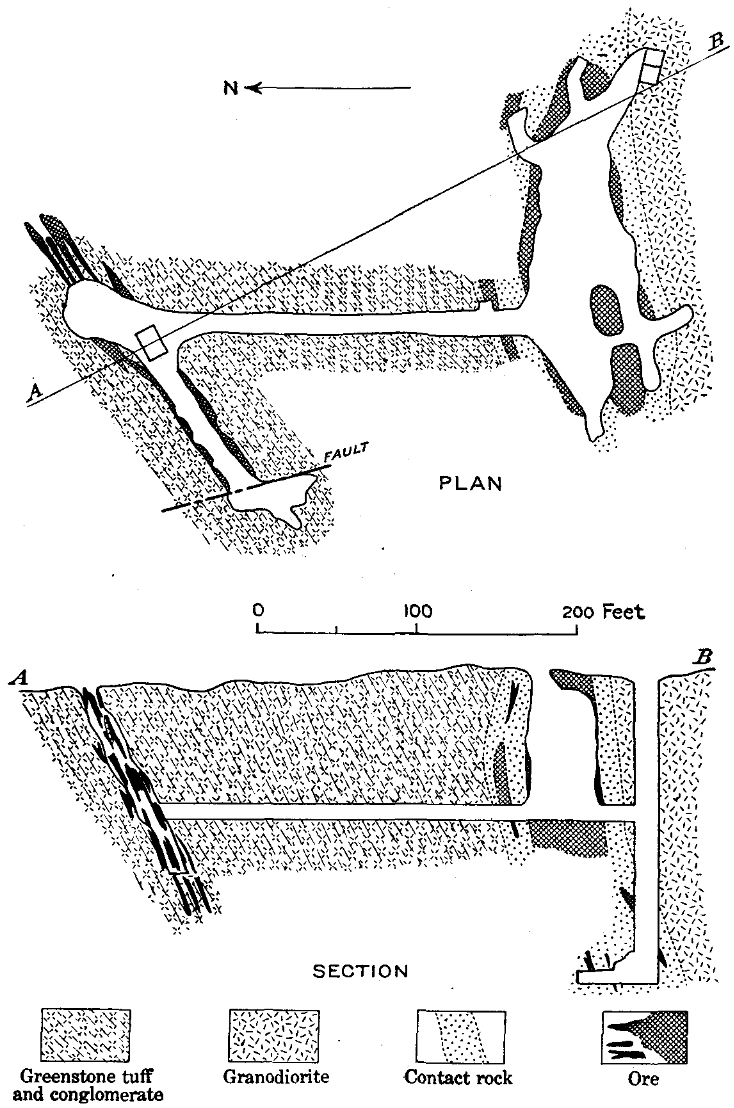


FIGURE 11.—Plan and section of the Rush & Brown mine (1908).

MAMMOTH GROUP.

The Mammoth group, including the Haida mine, lies on the east side of Kasaan Bay, about 6 miles from Kasaan and one-third of a mile from tidewater on the top of a low hill 500 feet in elevation. The property was largely developed in 1904–5 by the original owners, and in June, 1906, was sold to the Haida Copper Co., which began active developments and made plans for erecting a gravity tram 2,000 feet in length, extending to the beach, and a wharf and ore bunkers. In April, 1907, these improvements were completed and the company made shipments of ore to the Hadley smelter. Early in the summer, however, operations were suspended, and the mine has since been idle. The mine is developed by a tunnel 120 feet in length, connecting with a shaft 35 feet deep, which in turn connects with a surface pit on the ore body. In 1908 exploratory drifts had been extended from the tunnel, and prospect pits and short tunnels have been driven at other points on the property. Little work has been done at this prospect in recent years.

The ore body is an irregular magnetite mass carrying chalcopyrite in a gangue of garnet and epidote. The country rock in the immediate vicinity is made up of greenstone tuff and conglomerates, though just below the mine workings a belt of intrusive diorite is exposed which forms the western half of the ridge and probably underlies the ore body. The deposit is developed by an open pit over an area about 50 feet in diameter. This is undercut by a tunnel at a depth of 30 feet, and though the magnetite is exposed at this depth, chalcopyrite is not so abundant. To the northeast the ore body is limited by a fault plane striking nearly east and west and dipping 75° S. Other slipping planes striking at different angles were noted in the ore body and inclosing rock.

COPPER CENTER PROSPECT.

The Copper Center group of claims lies 1 mile north of the Mammoth group at an elevation of 400 feet. It was located in April, 1907, and in July was bonded to mining men who undertook its development. In 1908 several shafts from 10 to 30 feet deep had been sunk within an area 300 by 120 feet. In all these shafts and surface cuts magnetite and chalcopyrite ore associated with garnet-epidote and hornblende gangue is exposed. The deposit is apparently flat lying, though the amount of work done is hardly sufficient to prove that it does not continue in depth. It is also probable that further investigations at a greater depth will reveal deposits at other points on the property. The country rock is largely conglomerate and greenstone tuff, underlain by granodiorite, which is exposed down the hillside to the southwest. The area is densely covered by undergrowth, which renders prospecting difficult. The dip needle has been successfully used within this area, and the deposit just described was located by it.

CHARLES PROSPECT.

The Charles property is about 1 mile southeast of the Mammoth group and 5,000 feet from tidewater, at an elevation of 380 feet. It was located in May, 1907, and only a small amount of work has been done on it. The mineral body exposed in a cut 20 feet long and 10 feet deep consists of chalcopyrite masses associated with some magnetite in a garnet gangue which replaces the greenstone tuff country rock. Diorite occupies the hill just west of this prospect, but was not exposed near the mineral body. Dikes of diabase crosscut the ore body and are evidently of later origin. Besides the copper, the ore is said to carry high values in both gold and silver.

VENUS GROUP.

The Venus group of claims is on Iron Creek 1¼ miles from the head of Kasaan Bay and about 1 mile south of the Rush & Brown mine. This property was located in 1904 and a magnetic survey made. Within the area of maximum attraction a pit was sunk and a trench 50 feet in length was made through the overlying débris, exposing the magnetic deposit. Below these surface excavations, which are at an elevation of 250 feet, a tunnel 75 feet in length has been driven which crosscuts 50 feet of débris and 25 feet of country rock, and at its face exposes ore. The country rock is an indurated greenstone tuff with interstratified quartzite beds, the ore occupying a shear zone. Associated with the ore are considerable sphalerite and pyrrhotite, with quartz and calcite as gangue minerals.

PROSPECTS ON TOLSTOI BAY.

CHARACTER OF THE ROCKS.

On the north coast of Kasaan Peninsula, adjacent to Tolstoi Bay, which affords good anchorage, much prospecting has been done and numerous locations have been made, but none of the properties have been developed beyond the prospect stage. The small promontory here is composed largely of the diorite intrusive masses, which are exposed at Tolstoi Point and along the eastern slope of Tolstoi Mountain. On the western slope and along the east shore of Tolstoi Bay greenstone tuff, sandstone, and conglomerate and a few strata of limestone are exposed. Both the bedded and the intrusive rock masses are crosscut by dikes of porphyry and diabase. The ore bodies are contact-metamorphic deposits similar to those at the mines in the southern part of the peninsula. They are lenticular masses of magnetite carrying chalcopyrite and associated with garnet, epidote, calcite, and quartz, inclosed in the bedded rocks near the intrusive granodiorite contact.

IRON CAP GROUP.

The Iron Cap property, also known as the Mahoney group, consists of two claims on the northwest slope of Tolstoi Mountain at an altitude of 1,000 feet, reached by a trail 1½ miles long starting from a cove 2 miles southwest of Tolstoi Point. In 1901 the property was prospected to a considerable extent by open cuts along a gulch and by several hundred feet of diamond-drill holes, but since that time it has been idle. The country rock consists principally of greenstone tuff and a fine conglomerate intruded by syenitic dikes of considerable width, which are apparently related to the ore deposits. Three ore bodies have thus far been located, the largest 20 feet wide and traceable for 50 feet, the major axis striking N. 45° W. A second ore body, separated from the first by a 30-foot dike of altered syenite, is 12 feet wide and is limited on the footwall side (to the southwest) by a fault plane showing a considerable seam of gouge; toward the hanging wall it grades into a garnet-epidote contact rock. The third ore body, which lies just above the other two at an elevation of 1,080 feet, appears to be a flat-lying magnetite deposit only a few feet thick.

WALLACE GROUP.

The Wallace group includes four claims on the southeast slope of Tolstoi Mountain at elevations between 800 and 1,600 feet. At several places on this property small scattered masses of copper ore are exposed, but at no place have the explorations been sufficient to determine the extent of these deposits. The uppermost ore bodies found have been opened by a short tunnel which exposes a vein of garnet-epidote rock containing chalcopyrite. This vein strikes N. 15° W. and dips 20° SW. The lower openings expose a magnetite-chalcopyrite ore, but the bodies do not appear to be extensive.

TOLSTOI GROUP.

The Tolstoi group of claims is south of the Wallace group, just below the summit of Tolstoi Mountain. The ore bodies are low-grade magnetite-chalcopyrite masses similar to those on the Iron Cap group, but they have not been so extensively prospected. Only the required annual assessment work has been done on this property.

BIG FIVE CLAIM.

The Big Five claim lies half a mile east of Tolstoi Bay, on the trail to the Iron Cap group, at an elevation of 370 feet. In 1908 a tunnel 50 feet long and a shaft exposed scattered masses of chalcopyrite, pyrrhotite, and pyrite, in a gangue of garnet, epidote, and calcite. The mineralized mass is 10 feet wide and is a replacement deposit in limestone. Many slipping planes marked by gouge seams traverse both ore body and country rock. Assessment work only is done on this claim each year.

IRON ORE.

The only iron ore found in Kasaan Peninsula and the Copper Mountain area is magnetite, which occurs in large bodies along contacts of diorites and limestones. No special study has been made of these deposits, which have been developed only in connection with the mining of the copper ores. In the foregoing descriptions of the copper deposits, however, numerous references are made to the occurrence of magnetite.

The amount of magnetite shown at the surface is very large, and most of the ore is believed to contain no phosphorus or other detrimental impurities. The work at some of the copper mines has exposed a considerable quantity of magnetite, which carries from one-half to one and a half per cent of copper but which can not now be mined profitably as a copper ore. If the iron could be utilized, however, the copper, which could be separated magnetically after crushing, would furnish an additional source of profit. The utilization of these iron ores would seem to be a metallurgical problem, as there can be no question that they occur in quantities that should make them commercially valuable.

GENESIS OF THE ORES.

GENERAL PRINCIPLES.

In considering the probable source of the metal-bearing minerals that formed the ore deposits and of the mineral-bearing solutions that brought them from their original source and deposited them, with other minerals, in the fissures in the rocks, it should be remembered that, as in most other problems of this sort, certain theories or hypotheses as regards a supposed underlying igneous magma, the activities of mineral solutions, the precipitation of ores, and the metamorphic agencies and action are based on meager evidence. These hypotheses, however, appear to afford the most probable explanation of the condition now existing. The determination of the origin of an ore deposit is not only of scientific interest but of economic importance, for on this determination the miner must base his conclusions as to the depth to which the workable ore may extend and as to whether the ore will become more or less valuable with increase of depth. In most regions the workable deposits of copper ore are concentrations formed by circulating waters, generally of atmospheric origin, which have leached lean original ores and concentrated them as richer ore bodies in the immediate vicinity. On Copper Mountain and on Kasaan Peninsula, however, only deposits containing original or primary ores are found; few or no secondary ore deposits have been discovered.

The contact deposits are the principal valuable ores in these two areas and as they were formed dirrectly by metamorphic processes a discussion of these processes is necessary.

METAMORPHISM PRIOR TO THE GRANITIC INTRUSION.

The metamorphic changes in the stratified rock in the Copper Mountain area and on Kasaan Peninsula have already been described. Such changes were due primarily to heat, pressure, and solution and probably were intensified by the overburden of rock strata that has since been removed by erosion and by mountain-building forces or shrinkage of the earth's crust that caused lateral compression and folding of the beds. These forces produced what is known as regional metamorphism, causing a partial crystallization of the limestone beds, an induration of the gray-wacke, quartzites, and conglomerates, and a partial recrystallization and the development of schistosity in the more tuffaceous and argillaceous beds.

CONTACT METAMORPHISM.

DEFINITION.

In the districts under discussion the metamorphism of the intrusive igneous rocks and of the rocks they intruded is widespread and the processes that were involved in the changes that occurred are numerous. These complicated phenomena are classed under the term "contact metamorphism," a term that covers the mutual effects of the action on the intrusive and the intruded rocks.

The action of an intrusive mass of molten rock—an action that affects both intruded and intrusive rock—is in part recrystallization and in part replacement by added material. This action has its maximum effect at the contact of the intrusive masses and decreases with increase of distance from the contact.

CAUSES OF CONTACT METAMORPHISM.

Contact metamorphism is due largely to the action of superheated solutions derived from the eruptive magma and forced into the rocks, where it produced recrystallization, generally without notable addition or subtraction of material except in contact deposits, which represent an extreme type of metamorphic action and whose metallic content is supposed to have been contained in the superheated aqueous solutions. The presence of superheated steam or water in eruptive magmas is referred to by Gautier,[1] who makes the following statements:

Geological observations in all parts of the world show that thermal waters are usually related to ancient or modern volcanoes and that they issue from fissures of the same character as those occupied by metalliferous veins or igneous dikes. * * * [The quantity of water set free when granite is brought to a red heat is at least 25,000,000 to 30,000,000 tons (or $2\frac{1}{2}$ to 3 per cent of its volume) for each kilometer of this rock which is the least rich in water.] Thus the gases which I have extracted from rocks are composed of the same constituents as the volcanic gases. The vapor of water, free hydrogen, and carbon dioxide predominate in both, and both contain carbon monoxide, marsh gas, nitrogen, a little hydrogen sulphide, and traces of cyanogen and of petroleum compounds. This analogy of composition suggests an analogous origin.

Lindgren[2] makes the following statement:

Turning now to the large class of "epigenetic" deposits in which the metal is of later origin than the surrounding rock and has been introduced by agencies foreign to the rock itself, the first division which should receive attention is that of the contact-metamorphic deposits. In these the ores replace limestones or, more rarely, other sedimentary rocks, their substance is beyond reasonable doubt derived from metallic emanations from intrusive magmas, and their occurrence is closely connected with the actual contact with these intrusives, although they may extend for a couple of thousand feet away from the igneous rock. The deposits which generally contain magnetite and chalcopyrite and which usually are poor in gold and silver were formed at a considerable distance below the surface, probably never less than 1,000 feet, and there is, as far as known, no other limit in the depth at which they can be formed except that the heat must not be so high as to fuse the sedimentary beds.

In another paper on ore deposits and physical conditions Lindgren,[3] writing of ore deposits due to contact metamorphism of sediments by intrusive igneous rocks, says:

These deposits, which are almost exclusively of metasomatic origin, are apparently caused by replacement of calcareous rocks by very hot solutions given off by the cooling magma. These solutions were probably above the critical temperature and thus really in a gaseous condition.

Spurr[4] writes:

All rocks contain water, but the molten material contains more than the resulting rock. Most of this water is expelled at the moment of solidification, together with certain gases and a great variety of other materials held in solution. When rocks cool at the surface, the escaping water forms the clouds of steam, highly charged with gases and minerals, which issue from fissures, and when they solidify below the surface the waters and gases may be forced into the inclosing rock, producing that recrystallization and rearrangement of its constituents which is called contact metamorphism.

Kemp[5] makes the following statement in regard to magmatic waters:

That the floods of lava which reach the surface are heavily charged with them there is no doubt. * * * There is no reason to believe that many of the igneous rocks which do not reach the surface are any less rich, and when they rise so near to the upper world that their emissions may attain the surface we must assign to the resulting waters a very important part in the underground economy.

[1] Gautier, Armand, The genesis of thermal waters and their connection with volcanism: Econ. Geology, vol. 1, No. 7, pp. 688–697, 1906. Translation by F. L. Ransome of La genèse des eaux thermales et ses rapports avec le volcanisme: Annales des mines, 6th ser., vol. 9, pp. 316–370, 1906.
[2] Lindgren, Waldemar, Ore deposition and deep mining: Econ. Geology, vol. 1, p. 36, 1905.
[3] Lindgren, Waldemar, The relation of ore deposition to physical conditions: Econ. Geology, vol. 2, No. 2, pp. 105–127, 1907.
[4] Spurr, J. E., Relation of rock segregation to ore deposition: Eng. and Min. Jour., vol, 76, p. 54, 1903.
[5] Kemp, J. F., The problem of metalliferous veins: Econ. Geology, vol. 1, No. 3 (December-January, 1905–6) p. 229.

Lincoln,[1] writing on magmatic emanations, makes the following statements:

> Magmas contain certain substances which decompose or interact unless prevented by pressure or cooling. These generators give rise to primary magmatic emanations. Cooling or pressure or both cooling and pressure prevent the complete destruction of the generators, hence igneous rocks contain repressed emanations which may be expelled by heating them to red heat at atmospheric pressure.
>
> Intruded magmas by heating the adjoining rocks induce secondary emanations which consist of part of the potential emanations of these rocks. The ratio of primary to secondary emanations is an unknown quantity.
>
> Magmatic emanations which are expelled as gases and vapors become at the ordinary temperatures of the earth's surface solids, liquids, and gases. The principal gases are carbon dioxide, methane, hydrogen, hydrochloric acid, hydrogen sulphide, sulphur dioxide, nitrogen and oxygen with less carbon monoxide and ethane and a very little hydrofluoric, hydriodic, and hydrobromic acids. Water is the only important liquid, and it makes up a large percentage of the total emanation. The solids are chiefly chlorides and sulphates of the alkalies and alkaline earths and of iron, together with a much smaller quantity of metals and mineralizers.

DEVELOPMENT OF CONTACT METAMORPHISM.

As has already been noted, the intruded rock strata had been subjected to regional metamorphism prior to the intrusion of the igneous masses, which cooled and solidified at a considerable depth below the surface. It is therefore reasonable to suppose that the heat contained in the igneous rock masses at the time of their intrusion was gradually, though extensively, imparted to the intruded rock beds. It is reasonable to assume that while losing their heat both the intrusive and intruded rocks contracted somewhat at their contacts, leaving small open spaces and fissures in the contact zone, which permitted the metamorphic action to extend still farther from the contact. Around the intrusive contacts, especially at points where the line of contact is irregular, many cracks and fissures were formed, and along these local fractures the effects of contact metamorphism are most pronounced. The emanations from the igneous magma or mineralizing solutions ascended along these openings, dissolving and precipitating minerals and forcing themselves outward into the more or less porous wall rocks, where they caused replacement of the original mineral components of the rocks. The deposition of minerals from these solutions is attributed to supersaturation resulting from the decrease in the temperature and pressure of the solutions as they came into contact with colder rocks, but was probably to some extent due to precipitation of elements that entered the solutions on their upward course.

ORIGIN OF ELEMENTS CONTAINED IN MINERAL SOLUTIONS.

Whether the elements contained in the mineral solutions were derived directly from the magma from which the solutions emanated or whether they were derived from the rocks through which the solutions passed is not known, but it is probable that certain elements, such as iron, sulphur, and copper, found in the contact deposits and not in the adjacent rocks, were contained originally in the heated solutions. The lime and magnesia in the contact rock, however, are believed to have been derived by the solutions from the calcareous rocks through which they passed; the silica, alkalies, and alumina which have entered into the composition of the contact rock may, on the other hand, have been leached from the diorite.

METAMORPHIC EFFECTS ON THE INTRUDED ROCKS.

The character and extent of the contact metamorphism of the intruded rocks have been determined by many factors, such as the temperature, composition, depth, size, and form of the intrusive mass and the composition and porosity of the intruded rock strata. Though the results of metamorphism should be similar under similar conditions the amount of alteration varies widely from one point to another along the same contact and is besides dependent on the local development of fractures and fissures in the rocks along which the solutions circulated and produced the alterations noted. Extensive replacement of rock beds at certain localities and practically none at others indicates that the metamorphism is due mainly to the action of

[1] Lincoln, F. C., Magmatic emanations: Econ. Geology, vol. 2, No. 3, pp. 273, 274, 1907.

mineral solutions that were introduced along the contacts, and not so much to the immediate effects of heat and chemical reactions in the intruded rocks themselves at the time of the igneous intrusion.

The mineral solutions penetrated the sedimentary rocks most freely and produced metasomatism most readily along calcareous layers in the strata, completely altering them. In such beds diopside, garnet, epidote, and feldspar were formed, and in some places pyrite, pyrrhotite, and chalcopyrite are scattered through them. Limestone beds that lay at the contact are changed to marble and contain tremolite. Generally the line of contact with the limestone is sharp and is marked by the development of granules of diopside next to the intrusive rock and of tremolite in fine needles in the limestone. The contact rock contains included fragments and small masses of limestone and in places considerable calcite, which may have been formed by solution and reprecipitation of the limestone.

The calcite crystals usually form a matrix including diopside and garnet in irregular grains, and in some places appear to be the last mineral formed.

In the more porous strata, such as the schists and graywackes, there is not the sharp contact between the contact rock and the intrusives, except where the intrusive fills fissures that extend into the contact rock. These rocks appear to have been impregnated with mineralizing solutions which deposited in them garnet, epidote, diopside, feldspar, hornblende, wollastonite, tremolite, calcite, and some quartz, the first four minerals being confined to the contact zone and the last five minerals lying farther away from the contact. To what extent these minerals were formed by metasomatism of the rock beds without addition of material is difficult to determine; nor is it possible to say to what extent new material was introduced by the solutions.

METAMORPHIC EFFECTS ON THE INTRUSIVE ROCKS.

The direct changes caused by the adjacent igneous mass are relatively slight in comparison to the changes caused by the mineral solutions that passed along the contact and impregnated the rocks along the channels they traversed. The changes noted are essentially those of metasomatism and occurred after the intrusive mass had solidified. Greater changes were made in the intrusive than in the intruded rocks. In many places metasomatism caused by the solutions has been so great that the intrusive rock itself is entirely transformed into contact rock. Generally, there is no sharp line of division between the contact rock and the intrusive mass, the two grading into each other. In certain places fissure veins of contact rock enter the intrusive rock, but they do not extend far from the contact zone. The wall rocks around the contacts show here and there a slight veining, a few inches to a few feet wide. These veins are pegmatitic, consisting of large amphibole and plagioclase crystals with some pyrrhotite, diopside, and calcite. The feldspar in the diorite itself has been altered to scapolite, the alteration being attributed to the action of the mineralizing solutions. Where wide zones of contact rock occur the intrusive rock has been most altered and has contributed in large measure the material that makes up the contact rock, as is shown by analyses of the unaltered diorite, of the altered diorite at the contact, and of the contact rock itself, which are remarkably similar for rocks that differ so widely in mineral composition.

The main effects of the contact metamorphism on the diorite have been to change the feldspar (essentially alkaline) to scapolite and the hornblende to diopside and epidote. On passing from the unaltered diorite toward the contact one may note that the granitic texture gradually disappears, the rock assumes a dull and somewhat bleached appearance, the altered feldspar aggregates are separated by pale-green diopside and aggregates of epidote, and finally that the rock seems to be amorphous, of a pale-pink to greenish color, and felsitic in texture. This felsitic rock is made up almost entirely of scapolite, light-green diopside, some epidote in tufted aggregates, garnet in patches (in places connected with veins), and scattered particles of calcite. In the contact rock the original feldspar and ferromagnesian minerals are entirely replaced, though the rock still contains unaltered titanite crystals in considerable amounts, which were originally in the diorite, this occurrence emphasizing the fact that the alteration of the diorite has been extensive and that in certain places, at least, the contact rock is only a replacement of the diorite. The first alteration of the diorite was evidently accompanied by the deposition of pyrite, pyrrhotite, and molybdenite. Diopside seems to occur where pyrite is present and calcite with hornblende accompanies the molybdenite and magnetite.

DEVELOPMENT OF THE CONTACT ROCK.

Microscopic study of numerous specimens of the contact rock shows that it is in part altered wall rock, mostly limestone, and in part altered diorite, and that some of it has been formed by the filling of fissures in these rocks. The interior parts of several specimens of limestone that were included in the contact rock and of ores of the Jumbo mine are a finely granular white limestone containing considerable dolomite, which is bordered by a zone, a few centimeters wide, in which tremolite is abundant, and just outside of this zone is another zone, several inches wide, in which tremolite disappears and diopside is abundant. Garnet may accompany the diopside, and at a distance from the limestone may take its place, passing into a vein deposit with garnet druses. Usually, however, a deep-green amphibole appears at the outer border of the diopside zone, and beyond it the ores, chalcopyrite and pyrrhotite, become abundant, passing into solid masses of sulphide. Much of the rock of the contact zone consists of garnet and diopside with calcite, the diopside scattered and the garnet in part scattered and in part filling fissures.

The following analyses show the chemical composition of the several types of rock found at the Jumbo mine. The analyses were made from chips representing every type.

Analyses of specimens of rock from the Jumbo mine.

	1. Diorite.	2. Altered diorite.	3. Contact rock.	4. Limestone.	5. Garnet.	6. Orthoclasite.	7. Diopside.
SiO_2	59.44	46.57	39.51	0.61	35.18	62.03	55.12
Al_2O_3	17.40	13.51	5.87	.30	5.15	16.39	.40
Fe_2O_3	3.30	2.92	8.54	.48	25.05	.72	
FeO	2.77	2.73	3.40		.40	.86	1.12
MgO	1.81	2.85	5.08	8.00	.09	1.60	18.15
CaO	6.51	19.92	29.42	46.45	33.36	3.60	25.04
Na_2O	4.22	2.33	1.00			1.08	.45
K_2O	3.12	2.52	.64	.22		12.38	.02
H_2O-	.06	.33	.33		.42	.24	.17
H_2O+	.56	.53	.62			.61	
TiO_2	.66	.64	.29			.53	
CO_2	None.	3.40	3.68	44.07			
P_2O_5	.28	.27	.07			.13	
SO_3			Trace.				
S	.02			.06			
MnO	.17	.40	.62	.03			
BaO	.07						
SrO	.05						
FeS_2			.64				
MoS_2		.78					
	100.44	99.70	99.71	100.22	99.65	100.17	100.47

1 to 6 are analyses of rock from Jumbo No. 4 claim. Analysts: 1, 4, George Steiger; 2, 3, R. C. Wells; 5, W. T. Schaller; 6, Chase Palmer.
7 is a published analysis (Dana, E. S., System of mineralogy, 6th ed., p. 359, 1892) of a diopside at a diorite limestone contact at De Kalb, N. Y.

The analyses indicate that in order to derive a considerable part of the contact rock from the limestone by the development of such minerals as are abundant in the contact rock it would be necessary to add much silica, considerable ferric oxide, and some alumina, and to subtract a corresponding quantity of lime and carbon dioxide. It is assumed that solutions passing from the cooling intrusive rock performed these changes. The analysis of the altered diorite shows that it has lost such constituents as have been gained by the limestone and that it has gained much lime and carbon dioxide, constituents that the limestone has lost.

A specimen of the altered diorite at the contact with diopside-garnet-calcite rock had lost all its free quartz and most of its plagioclase, and in place of these it contained abundant calcite, considerable garnet, and much diopside. Its orthoclase was still present in nominal amount. Small patches of molybdenite accompanied the calcite. The molybdenite had clearly been introduced, for it was abundant in the adjacent contact rock. If this rock had lost orthoclase and had gained a little more garnet it could not be distinguished from the contact rock developed from the limestone. The analyses of the diorite, altered diorite, and contact rock show clearly that by subtracting the elements of the alkali feldspar—silica, alumina, and alkali—and adding the constituents of the limestone and of garnet the diorite could be transformed into the contact rock. The less altered diorite in places shows little change except the replacement of plagioclase by scapolite and the introduction of calcite.

Irregular veinlike bodies, which are generally the latest phase of the contact rock, vary in composition from pure garnet and nearly pure diopside to mixtures of orthoclase, calcite, and epidote, with or without diopside and garnet. A specimen from the Sultana claim simulates very perfectly the texture of coarse diabase. It contains long, lathlike intersecting crystals of nearly colorless diopside in a matrix of dark garnet and calcite in small amount in place of the garnet, suggesting that the diopside developed in limestone and that the garnet replaced[1] this limestone. The abundance of orthoclase unassociated with quartz is especially noteworthy. It occurs in very irregular branching masses a few inches wide, generally pink in color and very fine grained, even under the microscope, and consisting of orthoclase and calcite and masses of more coarsely crystalline epidote or diopside. These masses are probably closely related in origin to the syenitic form of the diorite, described as diopside-orthoclasite, an analysis of which is given in the table on page 40 (analysis 6).

Tremolite and diopside are found along the contact of the intrusive rock with massive limestone; wollastonite appears near the shaly limestones and is accompanied by much garnet and little or no diopside. The bands of garnet are sharply separated from the bands of wollastonite, the garnet probably occupying the place of shaly bands and the wollastonite that of the purer limestone. The absence of both tremolite and diopside near the shaly limestone is probably due to its lack of magnesia. Both these minerals are calcium-magnesium silicates, but wollastonite is a calcium silicate.

The contact rock is richer than either of the rocks inclosing it in ferric oxide, which is abundantly present in the garnet, and must have been introduced by the solutions that caused the contact metamorphism and the deposition of the ores.

The analysis of the contact rock in the contact deposits on Kasaan Peninsula does not show a great change in composition (see analysis, p. 83) because of the similarity in composition of the intrusive diorite and the intruded graywackes. The ore bodies, however, show that the copper and iron oxides and sulphides were introduced by the mineral-bearing solutions.

DEVELOPMENT OF THE ORE MINERALS.

The ore minerals occur chiefly near the limestone contact. With garnet and diopside, pyrrhotite and chalcopyrite are locally abundant in the recrystallized limestone. These ore minerals ramify in a meshlike structure through the calcite that incloses the diopside and garnet, and, in places, the amphibole. Finely outlined crystals of diopside are scattered thickly through the ore at some places in precisely the same manner as in the limestone. In other places, as at the Sultana claim, the ore occurs in parting and cleavage planes in shattered crystals of diopside and in veinlets of garnet. In a specimen from the Jumbo No. 4 claim the garnets that occur in the compact limestone of the wall rock are surrounded by thin shells of chalcopyrite.

Chalcopyrite occurs sparingly in the altered diorite in close association with calcite, which has been introduced into the diorite. Chalcopyrite and pyrrhotite are irregularly distributed in veinlike masses through that part of the contact zone which consists largely of garnet, diopside, orthoclase, calcite, and epidote. As developed in the contact rock this ore replaces calcite but not to any notable extent the other minerals.

In certain places the sulphide ores occur in distinct veins in the contact zone associated with epidote, quartz, orthoclase, calcite, a dark amphibole, magnetite, and, to less extent, diopside and garnet.

[1] The term "replacement" is used in this report in its broadest sense, meaning "taking the place of," without implying that solution and deposition have been practically simultaneous. However, the microscopic evidence that the plagioclase of the diorite altered directly to scapolite is as clear as could be desired.

PROGRESS OF MINERALIZATION.

The following view of the progress of mineralization in the contact zones is favored by the evidence. In the limestone tremolite (or wollastonite) and diopside were formed by the introduction of silica; later, and in part contemporaneously, garnet was formed by the combination of the lime (already present) with silica, ferric iron, and alumina, introduced by solution. While the quartz and feldspars were being removed from the diorite calcite, garnet, and pyroxene (diopside) were added. Afterward chalcopyrite and pyrrhotite replaced part of the calcite in the contact zone without notably affecting the other minerals. Later the fissures, which probably held the solutions during the period of active metamorphism, were filled with pyrite, chalcopyrite, magnetite, and the other minerals above enumerated. Finally upon the older vein minerals were deposited notably zeolite and calcite.

PROBABLE LIMITS OF TEMPERATURE.

The probable limits of temperature between which contact metamorphism took place can not be very closely determined. Wollastonite, which, for reasons already stated, appears to have been one of the first minerals formed in the contact zone, can not exist above 1190° C.[1] The garnet, some of which probably formed almost contemporaneously with the wollastonite, is a variety having distinct double refraction. Experiments made with this garnet by Dr. Merwin at the Geophysical Laboratory of the Carnegie Institution of Washington show that it loses its birefringence after it has been heated for a few hours at about 800° C., and does not regain it after several hours heating at 600° C. This fact indicates that most of the metamorphism took place at temperatures lower than 800° C.

Quartz occurs in the contact zone only in veins. Tests made on some of this vein quartz by F. E. Wright, according to the method described by Wright and Larsen,[2] indicated that it was formed at temperatures below 575° C. The vein quartz was formed, however, during the last stages of metamorphic activity.

[1] Allen, E. T., and White, W. R., On wollastonite and pseudowollastonite: Am. Jour. Sci., 4th ser., vol. 21, p. 89, 1906.
[2] Wright, F. E., and Larsen, E. S., Quartz as a geologic thermometer: Idem, vol. 27, pp. 421-447, 1906.

INDEX.