MINING IN THE LOWER COPPER RIVER BASIN.

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COPPER MINING IN CHITINA VALLEY.

INTRODUCTION.

During the summer of 1916 the writer visited most of the copper prospects of Chitina Valley (Pl. X, p. 156) to study their geology and learn what progress had recently been made in their development. The present activity of the copper market is reflected in the district by increased interest in prospecting for copper, and more particularly by the efforts of copper producers to maintain a maximum production of high-grade ore. No new mines that yielded a recorded output were opened in 1916, but shipments were made for the first time from a number of properties, some of which may become steady producers. The prospects will be described in the order in which they were visited, those in the western part of the field being considered first and those in the eastern part last. No attempt will be made to describe in detail all the prospects, nor is the space given to the description of any particular prospect an indication of its relative value. Some claims are described rather fully, because recent work on them has disclosed significant geologic facts or geologic relations, and one or two that have not been described before are described in detail.

The copper ores of the district extending from Kotsina River to Nizina are chiefly bornite, chalcopyrite, chalcocite, and oxidation products such as malachite, azurite, and covellite. Native copper, enargite, copper oxides, and some other copper-bearing minerals, among them tetrahedrite, are associated in places with the more common minerals first named.

Most of the copper deposits are found in the succession of ancient lava flows, long known as the Nikolai greenstone, that underlies the massive Upper Triassic (Chitistone) limestone of Chitina Valley. These lava flows are not a geologic unit, as was formerly supposed, but include in their lower part sedimentary beds and fragmental volcanic rocks deposited in water. Copper minerals occur in the older as well as the younger flows, although they are probably more common in the younger. At a few places deposits of copper minerals

have been found in the limestone (Chitistone) overlying the lava flows. The Kennecott-Bonanza and Jumbo mines are the best known of such deposits, and because of their great production of high-grade ore they have drawn particular attention to the limestone as a source of copper. Most of the copper prospects of Chitina Valley have already been described in more or less detail in publications of the U. S. Geological Survey.[1]

KOTSINA RIVER.

Most of the copper deposits of Kotsina River are in the upper part of the basin. The basin of the Kotsina, however, includes Elliott Creek, one of its lower tributaries, which by position and topography is detached from the main valley and is cut off from easy communication with it.

The copper claims of upper Kotsina River are, for the most part, in the hands of a few owners, who have done the assessment work required to hold the properties, but have not had the means to develop them and demonstrate their value. Claims are held on Copper Creek, Kluvesna River (including Mineral Creek), Kotsina River, and Granite, Surprise, Peacock, Roaring, Amy, and Rock creeks, tributaries to the Kotsina. A few claims have been dropped recently and others will probably be dropped, owing to the failure of the owners to interest capitalists in them. Although copper is the principal metal that has been sought in this district, silver has been found at one locality, where it may be present in sufficient quantity to make it of economic importance. It is contained in the mineral tetrahedrite and occurs in a zone of faulting and fracture west of the large granite intrusion between Kotsina and Kluvesna rivers. Several short tunnels have been driven on the claims, but because of the numerous faults they have not given a clear idea of the extent of the mineralization and the direction of the veins.

ELLIOTT CREEK.

The copper prospects of Elliott Creek are the property of the Hubbard Elliott Copper Co. and are represented by over 50 claims, some of which are patented. These claims extend along the upper part of Elliott Creek, principally on its north side, for nearly 6 miles. Bornite, chalcopyrite, and chalcocite are the most common copper minerals of the deposits.

For three years mining on Elliott Creek has consisted principally of assessment work on unpatented claims and the extension of the Albert Johnson tunnel on Deception Creek. When visited in August, 1916,

[1] Moffit, F. H., and Maddren, A. G., Mineral resources of the Kotsina-Chitina region, Alaska: U. S. Geol. Survey Bull. 374, 1909. Moffit, F. H., and Capps, S. R., Geology and mineral resources of the Nizina district, Alaska: U. S. Geol. Survey Bull. 443, 1911.

MAP SHOWING MINERAL RESOURCES OF LOWER COPPER RIVER REGION, ALASKA

Scale 1/500,000

10 5 0 10 20 Miles

1917

EXPLANATION

- Copper mine
- Copper prospect
- Gold lode prospect
- Gold placer
- Petroleum seepage
- Greenstone, Limestone — Limestone-greenstone contact

ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

this tunnel had been run to a length, not including crosscuts, of 1,076 feet, but preparations were under way for resuming work on it within a few days, and no doubt either the tunnel or a crosscut was extended considerably before the season ended. Work in the tunnel was not begun till late in the summer because of delays in the delivery of powder and because of difficulties in shipping that arose from labor troubles in Seattle. Power for the drills used in the tunnel is supplied by a small compressor plant driven by a gasoline engine. This equipment makes it possible to extend this tunnel much more rapidly and economically than the Elizabeth and Curtis tunnels, where hand drills were employed.

As the Albert Johnson tunnel, nearly all of which is in greenstone, approached the contact of the greenstone with the overlying limestone (Chitistone) shattered country rock and faulted-in masses of the limestone and shale that normally overlie the Chitistone limestone were encountered. A little farther from the face of the tunnel the drillers met a zone of crushed greenstone, which required timbering. This greenstone contains a little native copper, the only native copper that has yet been found in the tunnel. The ore that was exposed at several places by the tunnel is bornite and chalcopyrite in irregular veins which form part of a sheeted zone in the greenstone and are cut by faults later than the time of copper deposition. Because of this later faulting few of the copper-bearing veins can be followed far and many of them end abruptly against a wall of greenstone.

The Elliott Creek claims are now connected with Strelna by a new trail, which is much better than the one formerly used and which avoids the swampy areas traversed by the old trail.

KUSKULANA RIVER.

The copper prospects of Kuskulana River include the Copper Mountain group, at the head of Clear Creek; prospects on Porcupine Creek and Nugget Creek; the Finch group, between the forks of Kuskulana Glacier; the Pierson claims; the London and Cape claims, south of Trail Creek; the MacDougall claims; the Rarus group; and the Berg claims, or claims of the North Midas Copper Co., east of the Kuskulana and opposite the mouth of Clear Creek. None of these claims is now producing copper, but shipments of ore have been made from Nugget Creek.

The Copper Mountain group belongs to the Great Northern Development Co. and includes 58 claims on Clear and Porcupine creeks. Patent had been granted on 35 of these claims at the time of visit, and was expected soon on the remaining 23 claims. The development work consists of four main tunnels having a total length of more than a mile. Most of the work on these tunnels was done several

years ago, but owing to the destruction of the power plant by a snowslide and to uncertainty about the granting of patents, work was discontinued except so much as was required to hold the ground.

The copper ore is chalcopyrite or copper-bearing pyrite of low grade and is associated with a large body of diorite intruded in greenstone. Sulphides, especially pyrite, are present in the intrusive, but most of the copper sulphide is in the greenstone near the borders of the intrusive, where it occurs with pyrite in irregular veins and stringers and in small particles scattered through the greenstone. The ore is of low grade and must be mined on a large scale in order to be mined profitably. The owners expect to resume work when all the patents have been granted and propose to erect a plant to experiment with methods for saving the copper.

Several claims, in addition to those of the Great Northern Development Co., have been staked on Porcupine Creek. Most of them are near the borders of the intrusive rock and show the same copper minerals as the claims on Clear Creek. Several short tunnels have been started, but no extensive development work has been undertaken.

The claims on Nugget Creek belong to the Alaska Consolidated Copper Co. and are the only claims in Kuskulana Valley from which ore has been shipped. For a number of years the mining on this creek has been centered in the Valdez claim. The copper minerals occur along a well-defined fault which strikes N. 68° W. and dips 80° E. The common minerals are bornite, chalcopyrite, and pyrite. In places the copper minerals are accompanied by a gangue of calcite. Movement has taken place along the fault since the ore was deposited, so that in places both sides of the ore body are bounded by fault planes. The best ore so far encountered was at the surface and consisted of bornite and chalcopyrite in calcite. It was mined out and shipped to the smelter. As the deposits were followed downward the bornite diminished and the copper content became smaller, and along with this change pyrite appeared.

The development work now includes drifts at the 35-foot, the 50-foot, the 105-foot, and the 160-foot levels. The main or 160-foot level, called also the Lucky Boy tunnel, opens to the surface. A shaft 140 feet deep was sunk in the main level and a crosscut to the north was started from the bottom. This crosscut had been driven 60 feet at the time of visit in August and was advanced considerably before the summer ended.

The Finch group, on the mountain point between the forks of Kuskulana Glacier, belongs to the Alaska United Exploration Co. It includes 10 claims on which 3 short tunnels were driven and numerous open cuts were made. The copper minerals, which are chiefly bornite and chalcocite, are found along a shear zone trending approx-

imately northeast. Most of the prospecting has been done along this shear zone. A large disk-shaped mass of ore, a mixture of granular chalcocite, bornite, and quartz, is exposed near the highest tunnels, about 1,300 feet above the forks of the glacier. Its peculiar granular texture distinguishes it from any other ore in Chitina Valley known to the writer. It seems to be faulted off from a larger ore body, but the development work has not yet revealed the extension of the vein. Approximately 350 feet of tunnel has been driven on the Finch group.

The McConnell-Johnson or Mayflower claims are on the east side of Kuskulana Glacier, about 2½ miles above its lower end. The principal copper showing is about 1,000 feet above the glacier, on the east side of a deep gulch. The country rock is greenstone and is cut by a fault which strikes N. 50° E. and dips 75° N. Other faults and numerous fissures and joint planes are present, but the fault mentioned is the most prominent and is clearly defined by a steep, narrow gulch which follows it and was caused by it. Bornite, accompanied by quartz and epidote in variable quantity, is deposited along the main fault and in some of the minor faults, particularly near the intersection with a north-south fault. A few small, isolated lenses of bornite were also noticed in the greenstone away from the main fault. No physical connection between them and the fault was seen.

The development work includes several open cuts along the gulch, especially at the place where the ore is best exposed, and a tunnel on the east side of the gulch 75 feet long and 300 feet lower than the principal showing of ore.

The Pierson claims are near the lower end of Kuskulana Glacier and on the east side of the river, about 500 feet above the river level. Mineralization took place along the contact of the Chitistone limestone and a small dike or sill that lies between the limestone and the greenstone. The contact is a fault contact. A little copper staining is present, but free gold is reported by the owners and is regarded by them with greater favor than the copper. A short tunnel driven along the contact was caved at the time of visit and could not be examined.

The property of the London & Cape Co. includes 14 claims on the ridge southwest of Trail Creek. These claims were patented a number of years ago and no work has been done on them since the patents were issued. Copper stains are seen along fracture planes that cut the quartz-diorite country rock on the top of the ridge. A little work was done on the ridge, but more is represented by a tunnel on the Trail Creek side of the ridge, between 2,000 and 3,000 feet above the mouth of the creek. This tunnel was closed when visited, but is reported to be 245 feet long. It was begun to test the downward continuation of ore-bearing fractures on the ridge, but was not con-

tinued after the patents were obtained and is said to have no showing of copper.

The Rarus group was formerly part of the holdings of the Alaska Consolidated Copper Co., which dropped it in 1915, and it was restaked in 1916 by others. It is on the southeast side of Kuskulana River nearly 2 miles below Trail Creek. A tunnel 433 feet long and about 1,200 feet above the Kuskula was driven in a much faulted and metamorphosed mass of limestone and igneous rocks, including quartz diorite, hornblende-augite porphyry, and possibly greenstone. Some of the limestone is altered to highly garnetiferous metamorphic rock and some is silicified. A large quantity of magnetite in veins and irregularly shaped masses was introduced during the process of metamorphism. The ore body consists of pyrite and chalcopyrite or copper-bearing pyrite. Above the tunnel, as far as the base of the massive Jurassic conglomerate, the country rock is stained with iron and copper. The claims of the Rarus group include part of an area of contact-metamorphic rocks that extends northeast and southwest from the Rarus tunnel and that presents geologic conditions decidedly different from those at any of the localities so far described.

Northeast of the Rarus group is a group called the War Eagle, belonging to Angus MacDougall. A large quantity of magnetite is exposed on the claims nearest the Rarus roup and is the principal metallic mineral to be seen, although the rocks contain also pyrite and chalcopyrite. The development work done on these claims consists of open cuts.

Southwest of the Rarus and adjoining it are the Berg claims, belonging to the North Midas Copper Co. The geologic conditions here are similar to those at the Rarus group. The rocks include altered limestone, greenstone, and intruded light-colored diorite porphyry. They are extremely altered and are much faulted. The rocks carry magnetite, pyrite, and chalcopyrite, but these minerals do not occur together in all the prospects.

Four tunnels have been started on the property, three of which were driven prior to 1916 and have a combined length of nearly 1,150 feet. The fourth tunnel was in progress in 1916, and at the time of visit in August was 80 feet long, but since that time has been extended. Tunnel No. 4 surprised the owners by yielding high values in gold, so that the work in this tunnel was continued with the idea of developing a gold rather than a copper mine.

CHOKOSNA RIVER.

Only one group of claims is held in the area between Kuskulana and Lakina rivers, the Kinney-Golden property, on Golden Creek, a tributary of Chokosna River. The group consists of seven claims

strung along the contact of interbedded Triassic shale and limestone with Carboniferous (?) lava flows. Two parallel faults, about 500 feet apart, which strike east and dip south, have brought Triassic shale into contact with Nikolai greenstone and Chitistone limestone along one fault and with much older (probably Carboniferous) greenstone along the other. The geologic conditions are represented in figure 2.

A tunnel run at an elevation of approximately 4,200 feet was driven 200 feet through shale, Nikolai greenstone, and a light-colored porphyritic dike, into Chitistone limestone. The copper mineral is

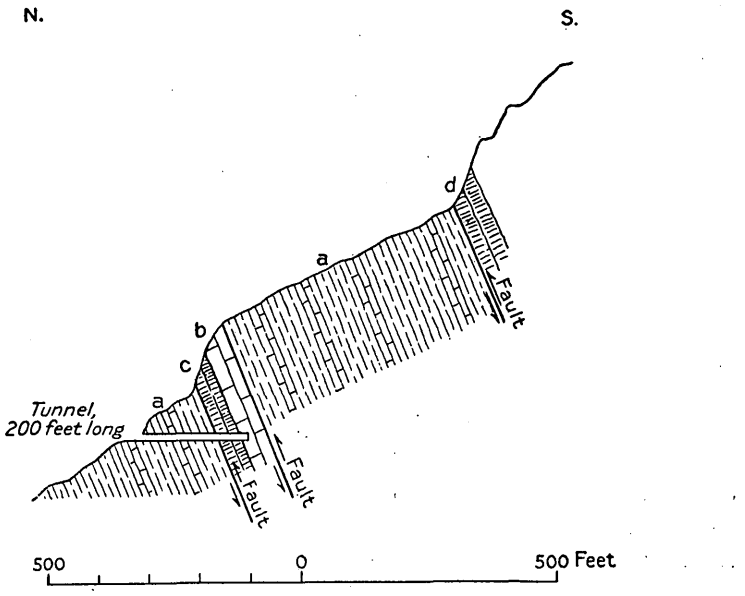


FIGURE 2.—Section showing geologic structure on Golden Creek. *a*, Shale and thin-bedded limestone (Upper Triassic); *b*, massive limestone, Chitistone (Upper Triassic); *c*, altered lava flows, Nikolai greenstone (Triassic?); *d*, altered lava flows, probably Carboniferous.

chalcopyrite and is best developed along the greenstone-limestone contact. In the claims farther east the limestone and greenstone disappear, leaving the two shale areas in contact, but copper is found along the southern fault contact, where several open cuts have been made.

LAKINA RIVER.

The property of the so-called Lakina Copper Co. includes 36 claims at the head of Lakina River. Prospecting has been done on both sides of the river near the lower end of the glacier, but attention is now given chiefly to one claim west of the river. A tunnel is being driven in greenstone at an elevation of about 2,100 feet above the bars of the Lakina at the mouth of Mill Creek. When the property

was visited, in September, the tunnel had been run to a length of 235 feet. It follows a well-defined shear zone that strikes N. 10° W. and dips about 70° W. The shear zone was traced northward up the mountain for nearly 1,000 feet vertically and apparently continues to the limestone on top of the mountain. It is exposed in open cuts and is marked by a leaching of the greenstone, caused by circulating waters. The ore in the tunnel, as exemplified by a hand specimen, seems to be all chalcocite but probably includes also bornite. Its gangue at some places consists of veins of coarse gray calcite, the largest 3 inches thick. At other places the chalcocite is accompanied by no gangue but occurs as veins in the greenstone or as grains disseminated through it. Most of the chalcocite, however, is found in veins along fracture planes. In the open cuts above the tunnel the copper mineral is bornite unaccompanied by chalcocite and in places is considerably oxidized. Several tons of ore was piled on the dumps awaiting shipment when the snow came.

The development work includes the tunnel and open cuts already mentioned and an excellent sled road leading from the Lakina at the mouth of Mill Creek to the tunnel. A wagon road follows Lakina River from Mill Creek to Long Lake on the Copper River & Northwestern Railway. This wagon road crosses the river by fords at several places and is not used at times of high water.

The property also includes several claims along the west side of Lakina River, where native copper occurs in greenstone in small veins, grains, and irregular bodies. Several small streams coming down from the mountain have cut deep gulches that lay bare the rock and expose the copper, which is scattered over the surface of the rock. No effort is now being made to exploit this copper.

In addition to mining claims the company holds a mill site on Mill Creek, where power for mining can be obtained with no great difficulty and in quantity sufficient for all needs.

KENNICOTT VALLEY.

A group of claims on Hidden Creek has been held for many years by the Tjosevig Bros. This property has recently changed ownership and is now being developed by the Josevig-Kennicott Corporation. The claims are on the south side of Hidden Creek along the contact of the Nikolai greenstone and Chitistone limestone. The chief copper mineral is bornite in stringers and irregularly shaped masses in greenstone. One of the chief obstacles to the development of this property has been the difficulty of transporting the ore to the railroad. Hidden Creek flows through a narrow valley that is shut in by precipitous walls and dammed across its mouth by Kennicott Glacier, which forms a lake that breaks out periodically when so

much water has accumulated that the ice can no longer withstand its pressure. A flood of this kind in 1916 did much damage to the railroad at McCarthy. Mining supplies have been carried along the lateral moraine of the glacier and finally over the glacier itself to the northeast side of Hidden Creek, and any ore that may be shipped now must be hauled over the glacier in winter. The new company proposes to build a tram over the mountain south of Hidden Creek and down along the Kennicott Glacier.

Eleven copper claims at the head of the north branch of Fourth of July Creek are owned by Woodin & Herman. The copper deposits are in the greenstone just below the base of the massive limestone that caps the mountains at the head of the stream. They are made up of bornite and chalcopyrite, and are typical of the greenstone deposits generally. Ore was being sacked at the mine in September in the expectation of hauling it by sleds over Fourth of July Pass and down Lakina River to Long Lake for shipment on the railroad.

A small area of coal-bearing rocks near this copper property has been known for many years. Its extent has not been determined, but claims have been staked on it and the coal may be valuable for local use if the copper deposits at the head of Fourth of July Creek prove to be extensive.

A group of claims on the point of mountains between the forks of Kennicott Glacier is held by the Great Northern Development Co. The south end of the point is made of Nikolai greenstone, which is overlain by beds of massive Chitistone limestone dipping about 30° N. Development and assessment work has been done for a number of years on claims along the contact. A promising body of ore was struck in the summer of 1916, and a contract was let in September for driving a tunnel during the coming winter to explore the ore further. The tunnel is high on the mountain, over 2,000 feet above the glacier, and is reached by a long trail from the south end of the low hills at the glacier forks. Supplies for use on this property are brought to a point on the east side of Kennicott Glacier about 3 miles above Kennicott and are sledded or packed across the glacier. Good traveling is found on the glacier and a crossing can be made at almost any time, for the ice is smooth and without bad cracks.

KENNECOTT MINES.

The Kennecott-Bonanza mine shipped its first ore early in 1911. Since then the Jumbo mine has been opened, and exploratory work has been started on the Erie claim. These properties all lie within 3 miles of one another, along the contact of the Nikolai greenstone

with the Chitistone limestone (Pl. XI) on the east side of Kennicott Glacier. They belong to the Kennecott Copper Corporation.

During the five years since 1911 a large quantity of high-grade copper ore has been shipped to the smelter from the Bonanza and Jumbo mines, and the mines themselves have been opened so as to expose the copper deposits and give a much more accurate idea of their extent and character than could be gained at the time when they were examined by Capps and the writer.[1] For this reason it seems desirable to describe these deposits more fully than the other deposits in the district, especially as such a description may be helpful to anyone who may be studying other copper deposits in the limestone. The writer acknowledges his indebtedness to those in charge of the mines for placing at his disposal every means for studying the copper deposits and in particular to Mr. H. D. Smith, Mr. E. T. Stannard, and Mr. A. M. Bateman for a great deal of information which a geologist who has not been closely associated with the work of exploration can not get readily, if at all. Although he had every facility for studying the ore deposits, the writer did not find it possible in the few days that were available for his work to do more than make a quick examination of the mine workings.

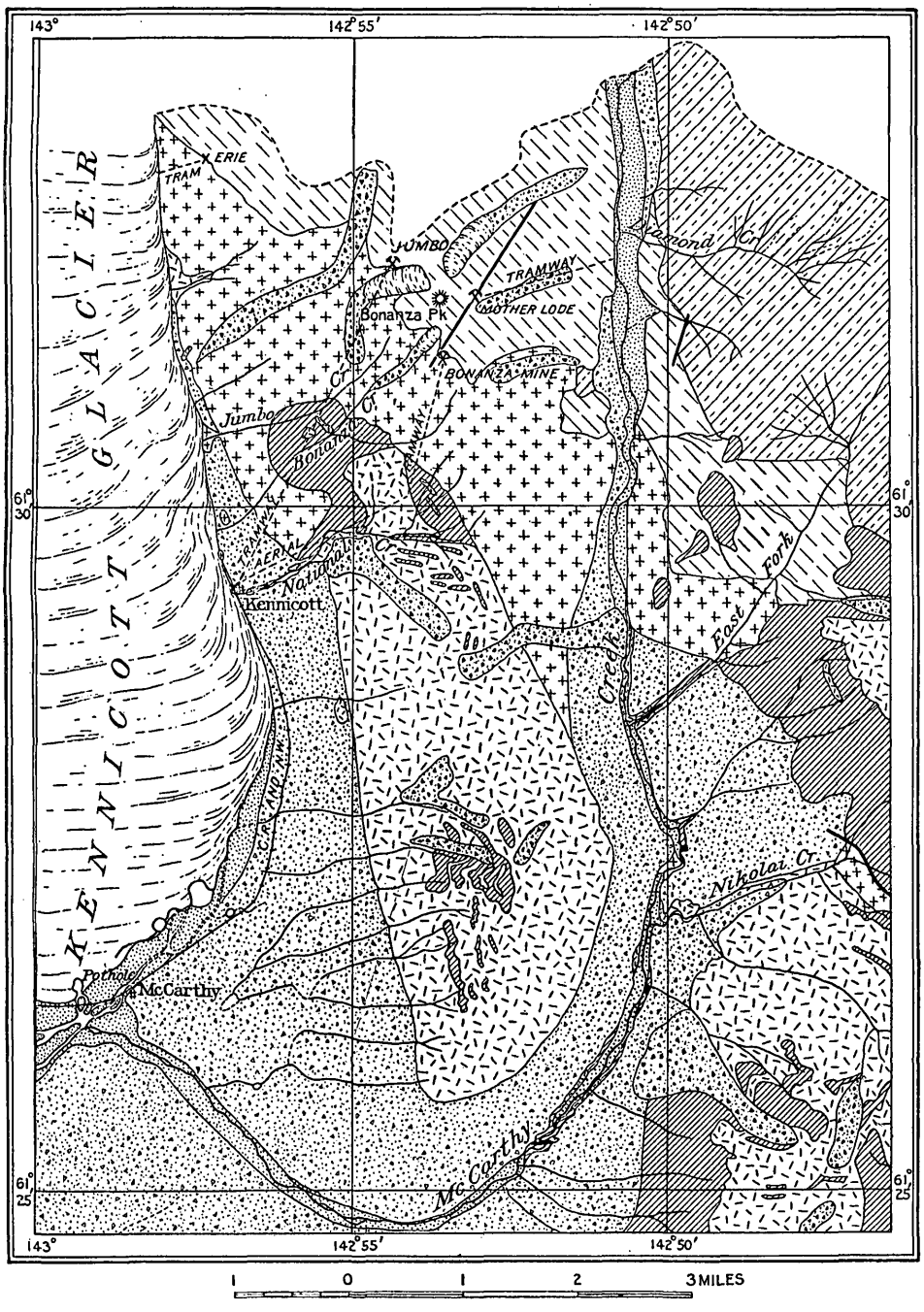
KENNECOTT-BONANZA MINE.

The Bonanza mine is in the mountains between Kennicott Glacier and McCarthy Creek, at an elevation of 6,000 feet (Pl. XI). The Jumbo mine is nearly a mile northwest of the Bonanza and a few hundred feet lower. The main tunnel of the Erie is $1\frac{3}{4}$ miles still farther northwest, at an elevation of 4,325 feet and within half a mile of the Kennicott Glacier.

The copper deposits of the Bonanza, the Jumbo, and the Erie resemble one another in the character of the ores and in the fact that they occur in the limestone only a short distance above the greenstone. It is therefore probable that they were formed at the same time and under the same conditions.

The Bonanza mine is on a sharp ridge that separates the heads of Bonanza and National creeks, tributaries of Kennicott Glacier. The head of National Creek valley is a glacial cirque; that of Bonanza Creek is also a cirque with a precipitous wall on the east, next to the mine. This cirque is still occupied by a small glacier. The ridge trends N. 30° E. From the mine the ridge rises steeply northward to the divide between Bonanza and National creeks and the basin of McCarthy Creek, but extends southward without much variation in elevation for half a mile and then drops off steeply

[1] Moffit, F. H., and Capps, S. R., Geology and mineral resources of the Nizina district, Alaska: U. S. Geol. Survey Bull. 448, pp. 84–92, 1911.



SKETCH MAP OF VICINITY OF McCARTHY AND KENNICOTT.

LEGEND

SEDIMENTARY ROCKS

Cenozoic

- Alluvium *(Gravels, sands, and silts of flood plains)*
- Rock glaciers
- Moraines and associated gravels *(Glacial till and glaciofluvial bench gravels, sands, and silts)*

QUATERNARY

Mesozoic

- Shales, sandstones, and conglomerates

JURASSIC OR CRETACEOUS

- McCarthy shale *(Shales and some thin interbedded limestones)*
- Chitistone limestone *(including, in upper part, the recently described Nizina limestone)*

UPPER TRIASSIC

IGNEOUS ROCKS

- Quartz diorite porphyry *(Intruded as laccoliths, dikes, and sills)*

JURASSIC OR LATER

- Nikolai greenstone *(Basaltic lava flows)*

TRIASSIC ?

Fault

Copper mine

Copper prospect

toward Kennicott Glacier. A trail up National Creek leads to the mine.

The geologic features are simple. On the south is the Nikolai greenstone (Triassic ?), a succession of ancient lava flows at least 5,000 feet thick. It is overlain by the massive Chitistone limestone (Upper Triassic), but is separated from it by a thin bed of shale, which has a maximum thickness of only 4 feet and is easily overlooked except in favorable exposures, because the base of the limestone is commonly covered by débris from the cliffs above. A typical profile across the limestone-greenstone boundary shows steep cliffs of limestone above a moderate slope in the greenstone, although at many places the greenstone is hidden by loose material, or "slide rock," as the prospectors usually call it.

The limestone between Kennicott Glacier and McCarthy Creek has a northwesterly strike and, in the vicinity of Bonanza mine, dips about 22° NE. It is cut by numerous faults and fractures, some of which had a most important influence in directing the course of circulating waters and controlling the deposition of copper minerals. The faults comprise, among others, the two systems that had most to do with the formation of the deposits. One system is distinguished by fractures with steep dips and with approximately northeast strikes; the other by fractures with practically the same strike and dip as the limestone beds. Both fault systems probably originated at about the same time. They are intersected by steeply dipping cross faults, either of the same age as the major faults or possibly older, along which the copper-bearing solutions spread out for a short distance from the main fractures. They are also crossed by fractures that originated after the ore was deposited.

The ore-bearing faults and fissures of greatest importance among those just mentioned belong to a zone of fracture and faulting that extends N. 30° E. This zone is made up of steeply dipping faults and fractures that strike N. 30°–70° E. and that, together with the bedding-plane faults, were most effective in directing the flow of mineral-bearing waters.

The bedding plane or "flat" faults indicate movement of one limestone bed on another or movement along a plane parallel or approximately parallel to the planes of bedding. Such movement, however, was not restricted to planes of bedding, for in places the "flat" faults are slightly wavy and cross limestone beds at a slight angle to their bedding planes. Bedding-plane faults occur in the lower part of the Chitistone limestone at many places throughout Chitina Valley, and at least four are recognized in the Bonanza mine. The contact of limestone and greenstone in particular was a place of movement, which was facilitated, no doubt, by the thin

bed of shale at that place. Evidences of such movement are found in the shale bed at Bonanza mine.

Two principal cross faults are seen in the Bonanza mine, the Mammoth, which strikes N. 52° W. and dips 70° N., and the Azure, which strikes N. 62° W., dips high north, and is in reality a shear zone about 100 feet wide, made up of minor nearly parallel faults. The Mammoth fault produced a displacement of less than 20 feet in the limestone beds and is older than the ore. (See p. 167.) The Azure fault is a normal fault that caused very little displacement. Movement has taken place along this fault since the ore was deposited, but the faulting may have begun earlier. Much of the limestone along the fault zone is crushed. The direction of latest movement in the Azure fault is indicated on slickensided surfaces by striae that dip 70° W.

Although the Mammoth and Azure faults are the most conspicuous of the cross faults in the Bonanza mine, many other cross faults having the same general strike cut the principal ore-bearing fissures. Some of them are manifestly later than the ore, for they offset it. Some of them carry small quantities of ore, as may be seen on the 400, 500, and 600-foot levels. It appears not improbable that cross faults were produced when the principal shear zone was formed and that movement took place along some of the faults of both sets after the ore was deposited.

It is difficult to make more than qualitative statements in regard to the displacements produced by faulting except as to a few of them. The vertical displacement along steeply dipping faults is slight. Some of the movement, particularly along faults that run north and south, was nearly horizontal, or parallel to the direction of the present dip. The displacement in this direction is small but greater than that in the direction perpendicular to the bedding planes. Displacement along the bedding planes is difficult to measure because reference points are lacking, but in some places not far distant from Bonanza and Jumbo mines it is considerable, amounting to hundreds of feet.

Close examination of the rocks adjacent to the contact between the Chitistone limestone and the Nikolai greenstone at the Bonanza mine disclosed the following section:

Section at Bonanza mine.

	Feet.
Limestone, magnesian, granular, ore-bearing.	
Fault; in places forms contact between magnesian and nonmagnesian limestone.	
Limestone, dark gray, nonmagnesian	50–60
Limestone, siliceous, containing a little pyrite	20
Shale, red or green	4
Greenstone, amygdaloidal (Nikolai).	

The first large ore bodies found were in the magnesian limestone, so that at one time it was supposed that this rock had controlled ore deposition, and exploratory work was conducted accordingly. As the work proceeded, however, this supposition had to be given up, for ore was found in both the magnesian and the nonmagnesian limestone. At some places a fault approximately parallel to the bedding planes separates the magnesian and nonmagnesian limestones, but at others the contact of the two is defined neither by a fault nor by a bedding plane but crosses the bedding planes irregularly.

The list of copper minerals in the ores of the Kennecott-Bonanza, formerly thought to include only chalcocite, covellite, and copper carbonates, has been extended as underground work proceeded and now includes chalcocite, covellite, azurite, malachite, enargite, bornite, chalcopyrite, bluestone or chalcanthite, and possibly other minerals. The ore is dominantly chalcocite. Covellite, like azurite and malachite, is common and, at least in some places, seems to be a product of the alteration of chalcocite. It forms veinlets that cut the chalcocite and it coats with tiny crystals the surfaces of open spaces in the chalcocite. Enargite is rare but is found in the 150-foot and 300-foot levels. Bornite is found throughout the mine and chalcopyrite in the lower levels, though it is uncommon.

The ore occurs as great tabular replacements of limestone along "vertical" faults, as tabular replacements along "flat" faults, as irregular-shaped masses, as networks in brecciated limestone veined with calcite, and as veins that have replaced limestone along bedding planes and that are in places only a few inches apart.

The great ore bodies belong primarily to the "vertical" fault system and have been found at the intersection of the "vertical" with the "flat" faults. They lie above the "flat" fault and terminate sharply against the underlying limestone, yet copper ore is found along "vertical" fissures below the "flat" faults at some places, as in the "little Bonanza" open cut at the south end of the ore body. The "little Bonanza" is a mass of chalcocite, covellite, copper carbonates, and chalcanthite in "vertical" fissures of the main fault system, which lies on the west side of the ridge and extends down to the shale. It was not exposed to view until the talus material had been cleared away.

The largest ore bodies so far uncovered were found at the south end of the mine. They followed fissures striking N. 50°–70° E. and were adjoined on the north by smaller bodies striking about N. 30° E. The formation of the larger deposits was much influenced by the Mammoth fault, for, although the limestone beds were not greatly displaced by the fault, the copper-bearing solutions spread out along it and produced local enlargements of the ore bodies. South of the fault the ore reached a width of about 80 feet, but a short distance

north of it the width was much reduced. The Mammoth fault appears only in the upper levels, for it crosses the south end of the ore body and reaches the northeastward dipping surface of the greenstone between the 200 and 300 foot levels.

The "vertical" bodies of the higher levels had a high westerly dip, which increased in steepness as the ore was followed in depth toward the northeast. Ore was mined in the main fissure system to a width of 85 feet.

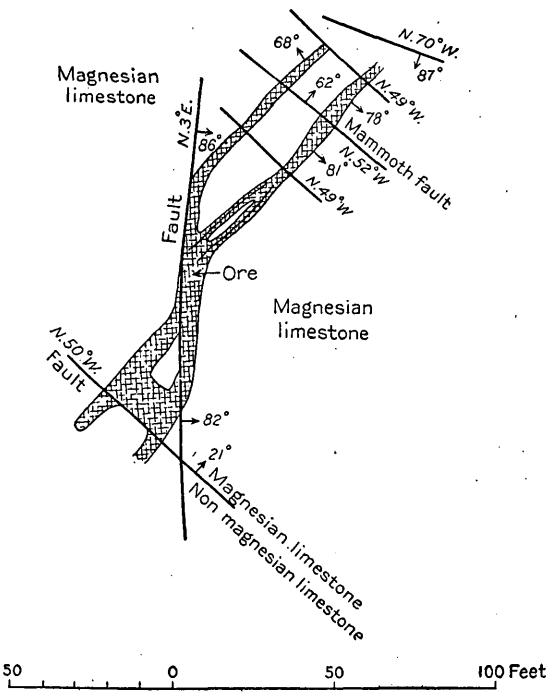


FIGURE 3.—Sketch showing displacement of ore body along a vertical fault, 100-foot level of Kennecott-Bonanza mine. From mine map.

The ore is cut by faults that show little displacement, at least not much is shown by the steeply dipping faults. The Azure fault is over 800 feet northeast of the Mammoth fault. It appears in the 300 to 600 foot levels and meets the greenstone between the 600 and 700 foot levels. Movement took place in it after the ore was formed. Three other principal "vertical" north-south faults offset the ore bodies, as is evident at the surface and in the 100-foot level of the mine. Such faulting as that indicated in figure 3, however, apparently took place before the ore was deposited and offset the two earlier faults, which the ore-bearing solutions followed later.

The north-south fault caused displacement chiefly in a horizontal direction. One of the striking features of the ore deposits is the sharpness with which they are limited by some of the fault planes. In many places a thin gouge, scarcely thicker than a sheet of paper, has been sufficient to prevent the solutions from reaching the limestone on one side of the fracture while that on the other was being entirely replaced. The gouge along the fault planes is locally highly colored with iron oxide.

The exposures at the surface of the Bonanza mine show no more oxidized ore than those in some of the lower levels. Oxidized ore

continues to the lowest (700-foot) level and is evidently most abundant where the ore was faulted and crushed and where water could therefore circulate freely. Oxidation is at some places confined to one side of a tight fault. Locally the chalcocite is brecciated and much oxidized, showing kernels of original chalcocite in oxidized ore. The Bonanza is at present a dry mine.

The mine workings have now reached the 700-foot level. The main or adit level is the 150-foot level. From the adit level an incline runs nearly parallel to the contact of limestone and greenstone and descends to the 600-foot level. From the incline, in turn, levels are driven off northeastward into the ore body. A winze has been driven from the 600-foot level to the 700-foot level. The 300-foot level connects by a short raise with the McCarthy Creek side of the ridge. Much high-grade ore, including most of that exposed originally at the surface, has been mined above the adit level, through which it has been drawn off. In this mine thorough exploration is necessary to trace the ore; all small veins and stringers must be closely followed, for many of them develop into valuable bodies of ore within short distances.

JUMBO MINE.

The copper deposits of the Jumbo mine resemble in most respects those of the Bonanza. The mine is in the Chitistone limestone, near the head of Jumbo Creek, just above the contact of the Chitistone with the underlying greenstone. Jumbo Creek originates in a small glacier on the west side of Bonanza Peak and flows southwestward to Kennicott Glacier, which it joins 1¼ miles north of Kennicott. The glacier is confined on the north and east and for some distance on the south by precipitous cliffs of limestone. The Jumbo mine is in the north wall of this cirque, nearly half a mile from the head of the glacier. All the mine buildings are set on the glacier.

The geology of the mine is practically the same as that of the Bonanza. A stratigraphic section shows greenstone at the base overlain by 2 feet of shale. Then come, in ascending order, about 20 feet of siliceous limestone containing a little pyrite, 50 to 60 feet of dark-gray limestone, and finally granular magnesian limestone. In the adit or 180-foot level of the mine the limestone beds strike N. 50° W. and dip 34° N. The dip is therefore a little greater than at the Bonanza and the strike is a little more westerly. A short distance east of the entrance of the 100-foot level of the Jumbo a light-colored porphyritic dike 2 feet thick intrudes the limestone. It has not yet been encountered underground.

A fault zone whose general course is a little south of northeast cuts the limestone but displaces the beds very slightly. It comprises

fissures and minor faults that range in strike from N. 60° E. to east and a few that strike about N. 30° E. This fault zone is made up of the principal ore-bearing fissures. Near the outcrop of the ore the dip of these fissures is 70°–80° W., but as the fissures are followed to the northeast the dips become steeper and in some of the faults are southeast.

The main fissure zone is cut by cross faults that trend north-northwest and by a few that trend north. At one locality the ore is displaced 1 foot by a fault that trends north and at another place 2 feet by a fault that trends north-northwest.

Of much more importance than these cross faults are the bedding-plane or "flat" faults. In the Jumbo mine, as in the Bonanza, the bed of shale between the limestone and the greenstone is evidently a plane of movement, for wherever the shale is exposed it is crushed to a thick gouge. The fault along the shale bed has apparently a much less significant relation to the copper deposits than the fault immediately below the rich ore bodies. This fault is about 80 feet above the greenstone and is in places made up of several closely spaced parallel faults. It does not strictly follow the bedding planes but crosses the bedding at a slight angle, and on the 500-foot level it strikes N. 70° W. and dips 35° N. It is cut by all the levels and marks the bases of the rich ore bodies. Movement along this fault plane after the ore was deposited is indicated on the 180-foot level by a fault breccia containing a little chalcocite. Although this postmineral movement has taken place, the original displacement occurred before the ore was deposited.

The ore of Jumbo mine is prevailingly chalcocite, but includes a subordinate quantity of copper carbonates, as well as enargite, bornite, and chalcopyrite. In places covellite is associated with the chalcocite. According to Mr. H. D. Smith, in charge of the mining, if the proportion of chalcocite and carbonates that can be distinguished by the eye is estimated as 98 per cent, then 1.9 per cent will represent the covellite and 0.1 per cent the bornite and chalcopyrite. This estimate is, of course, only approximate, but it indicates the relative quantities of the copper minerals in the ore. The ore from the Jumbo mine shows more oxidation than that from the Bonanza. The carbonate ore consists generally of malachite and azurite, but that in certain stopes includes malachite alone. Silver occurs with the copper at the Jumbo mine as well as at the Bonanza. The proportion is slightly variable and ranges from 14 to 16 ounces to the ton of high-grade ore. The silver content of chalcocite near fissures is less than that found at a distance from them, a fact demonstrated by careful assaying. The width of the ore-bearing ground worked is not less than 240 feet, yet the limits of the ore have not yet been reached.

In form the ore bodies are like those of the Bonanza. The large tabular masses of chalcocite replace limestone along the northeasterly striking faults, but all openings in the fractured limestone along the fault zone were invaded by the ore-bearing solutions so that stockworks and irregularly shaped bodies are common.

Ore was deposited in great quantities at the intersection of the "vertical" and bedding-plane faults between the 400 and 600 foot levels. The "vertical" faults here strike N. 65° E. and dip steeply to the northwest. The bedding-plane fault strikes N. 72° W. and dips 34° N. The great ore body was on the southeast side of the main "vertical" fault and lay for the most part, but not entirely, above the bedding-plane fault, between it and the magnesian limestone. It extended from a point a short distance above the 600-foot level to a point 30 feet above the 400-foot level. In projection on a horizontal plane it had a length of 400 feet. At its lower end was an open cave in the limestone, partly below and partly above the fault. A horizontal section of the ore body at the 500-foot level is shown in figure 4.

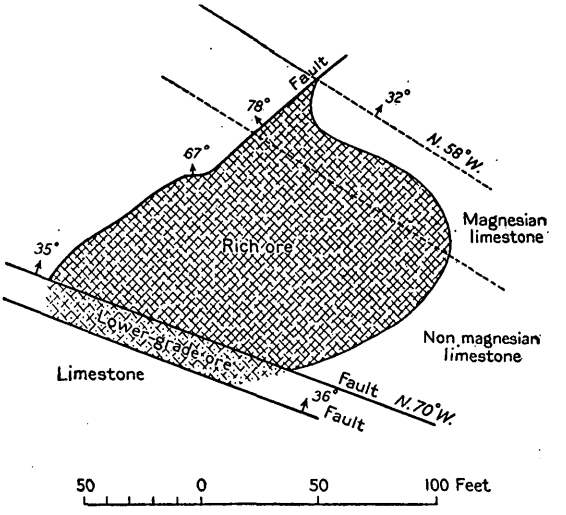


FIGURE 4.—Horizontal section of the ore body in the Jumbo mine on the 500-foot level. From mine map, slightly modified.

This great mass of ore was practically solid chalcocite, with which was mixed an almost insignificant quantity of included limestone, largely altered to residual clay. It yielded 50,000 tons of copper ore, much of which ran 76 per cent copper. This massive body of chalcocite was at the 500-foot level, bounded on its lower side by a bedding fault, but below this fault there was ore of lower grade which was terminated, 6 to 8 feet lower, by a second fault parallel to the first, beneath which no ore was seen except a few tons at one place.

A map of the 500-foot level shows, in addition to the ore body just described, two principal tabular ore bodies along parallel "vertical" fractures extending northeastward and other irregular-shaped bodies. On the 700-foot level also there were two main fissures at the northeast extension of the drifts. The sharp, clean-cut boundaries between limestone and chalcocite and the total absence

of gangue minerals except calcite are striking features of the ore deposits both here and at the Bonanza.

The main adit of the Jumbo mine is the 180-foot level. This level penetrates between 200 and 300 feet of greenstone before entering the limestone. From this level an incline with a slope of 33° to 34° descends to the 700-foot level, in which a shaft is being sunk. The incline was started with the expectation that it would penetrate barren ground away from the ore body, but it encountered much high-grade ore. Intermediate levels were driven to the northeast from the incline into the ore bodies, just as they were at the Bonanza.

ERIE CLAIM.

The Erie claim is a little more than 3½ miles north of Kennicott and less than half a mile from the glacier. Three prospecting tunnels have been started on the claim. The principal tunnel was run on the largest showing of ore, 1,575 feet above the glacier, at an elevation of 4,325 feet. It is driven in limestone at the contact of the limestone and greenstone. The boundary between these formations in this vicinity runs nearly northwest, following the base of a limestone wall that rises above steep slopes in the greenstone. The steepness of the slopes and the absence of talus in many places give unusual opportunities for examining the shale between the limestone and the greenstone. The shale gives clear evidence of movement along the bedding and in places shows copper staining. Another tunnel, on which considerable work has been done, is 215 feet lower and a short distance to the west. A short tunnel, on which little work has been done, is about 100 feet lower and still a little farther northwest. All three tunnels are in limestone just above the limestone-greenstone contact.

The geologic structure at the Erie mine differs from that at the Bonanza and Jumbo mines chiefly in the faulting, which has here apparently been more pronounced and less restricted to narrow zones. A number of displacements by faults that cross the contact were seen, and at one place a wedge-shaped mass of limestone and greenstone had been thrust up into the limestone nearly 20 feet without disturbing the parallelism of contact and bedding planes. A wide area of the limestone is cut by minor fractures in which copper minerals were deposited.

All the copper minerals seen at the Bonanza and Jumbo mines are found in the Erie—chalcocite, covellite, enargite, bornite, chalcopyrite, and carbonates. The Erie ore so far uncovered is much more oxidized than that of the Bonanza and Jumbo mines.

The middle tunnel was started on a vein of carbonate ore along an east-west fault having a southerly dip. It was driven eastward for

a short distance till it encountered a small light-colored dike striking N. 22° W. The dike cuts the ore and was itself fractured and slightly displaced by later movement along an ore-bearing fault which strikes N. 35° E. and has a steep easterly dip. This fault or others approximately parallel to it was followed northward in order to reach the magnesian limestone, then supposed to be the copper-bearing rock. At 400 feet from the mouth of the tunnel a cross-cut was driven. The fissures of the main fault system carry copper minerals, but not in sufficient quantity to give much encouragement for mining. They are cut by eastward-trending faults, some of which, like that at the mouth of the tunnel, carry copper. At least one well-defined bedding fault was encountered. No alteration of the limestone near the dike was noticed, and in fact alteration near small dikes in this district is unusual, although local enlargements of the dikes have produced decided alteration of the limestone in places at the head of Lakina River.

About 30 feet south-southwest of the mouth of the tunnel is an incline, 40 feet deep, sunk in limestone along the plane of a fault that brings greenstone and limestone into contact. The fault strikes N. 30° E. and dips approximately 60° E. It is a normal fault, for the greenstone lies on its west side. A small quantity of good high-grade copper ore was taken from the incline.

The upper, larger tunnel extends in general east-northeast, the principal direction of fissuring, but is somewhat winding, for it followed the ore, which is not confined to a single fissure and is besides here offset by cross faults. Fracturing is pronounced and the ore is distributed irregularly. Two cross faults have produced displacements of 15 and 20 feet in the main ore fissure. Some of the cross faults carry copper minerals in small amount.

At the time of visit this tunnel has been extended about 700 feet and two shafts had been started in it. These shafts are steeply inclined, following the plane of a fault or faults that dip 70° to 80° S. The shallower of the shafts, that nearer the tunnel mouth, is about 40 feet deep and shows a displacement of the beds but has not been sunk deep enough to determine the amount of the displacement. The second shaft is about 65 feet deep and shows that the beds on the hanging wall side have moved upward, relatively, a distance of 20 feet. A sublevel about 200 feet long was being driven from the bottom of the deeper shaft. It follows ore-bearing fissures, but the fissures make a slight angle with the fault that displaces the limestone and greenstone, and thus in going eastward the tunnel is gradually separated from the fault. Considerable high-grade ore was encountered along the sublevel.

The Erie ground has been more shattered than that at the Bonanza and Jumbo mines. The displacement by faults is greater, and the

migration of copper-bearing solutions through the country rock is greater, at least on the surface exposures.

North of the camp, near and somewhat above the lower tunnel, is a small gulch which is separated from the camp by high limestone cliffs and a small ridge. The southern side of the gulch is a dip slope, the northern side a limestone scarp or wall. The surface of the beds on the south side shows a network of calcite veinlets that have filled fractures in the crushed limestone. Associated with these veinlets of calcite are veinlets of chalcocite, some of them no thicker than paper, in which the chalcocite has been in large part altered to azurite. The limestone is intruded by a dike about 2 feet thick, which has the same dip as the slope of the scarp on the north side of the gulch and in places forms the face of the scarp. The limestone is also cut by northward-trending vertical faults, along which it is darker and much harder or more resistant to weathering than the unaltered rock, so that the veins of calcite in the fault and in the limestone adjacent to it for a width of a foot or more stand out in relief. Several such faults, from 10 to 20 feet apart, were seen. They indicate slight movement in the limestone and carry chalcocite, mostly altered to azurite. Similar copper veins were seen in the bedding planes of the limestone. The whole mass makes an ore that may perhaps be mined profitably.

The Erie claim is equipped with an aerial tram, 2,700 feet long, run between the lateral moraine of Kennicott Glacier and the upper tunnel. A trail leads from the lower end of the tram to Kennicott. A quantity of high-grade ore, mined from the tunnels, was ready for shipment as soon as snow should make sledding possible.

Ore from the Bonanza and Jumbo mines is brought to the mill by aerial trams. The tram to the Bonanza mine is 2.8 miles long and has one angle station. That to the Jumbo mine is almost 3 miles long and leads directly from the mine to the mill. These two trams together have a capacity of over 800 tons daily.

Most of the ore shipped from Kennicott is of high grade and requires no concentration. Part of it, however, is concentrated in the mill, the tailings from which are treated in the leaching plant with ammonia, which dissolves out the copper carbonates. By this means 65 to 72 per cent of their content of copper is recovered from tailings that carry from 1.5 to 2 per cent of copper. The loss is probably due to the fact that fine particles of chalcocite are not affected by the ammonia. Much experimental work has been and is being done to perfect the leaching plant. The difficulties encountered have been mechanical rather than chemical, chief among them being the difficulty of removing the precipitate from the still.

The shipments of ore from Kennicott in August, 1916, amounted to 8,500 tons. During the same month 800 tons of ore was concentrated

in the mill and 80 tons of fines was treated in the leaching plant. It was planned to run the mine at full capacity through the coming winter and to mill about 750 tons of ore a day. Full production has not been maintained in winter during preceding years, chiefly because of the lack of water and the difficulty of disposing of tailings before they have frozen.

MOTHER LODE MINE.

For several years the Mother Lode Co. has done development work on claims on McCarthy Creek, northeast of the Kennecott-Bonanza mine, and since 1913 has made shipments of ore each winter. The ore is chiefly chalcocite but contains a large proportion of covellite, azurite, and malachite, derived by oxidation from the chalcocite. It occurs along a shear zone that cuts the Chitistone limestone and strikes N. 30° E. Besides copper, the ore carries silver in the ratio of 1 ounce of silver to each 4 per cent of copper.

The deposits so far exposed are high above the limestone-greenstone contact, and in this respect differ from the ore bodies of the Bonanza and Jumbo mines, which are near the contact. A second point of difference is the much greater proportion of oxidized ore in the Mother Lode deposits.

Nearly 7,000 feet of tunnel, shaft, and raise have been driven in the ore body since the mine was opened, and as a result of the present season's work 14 carloads of ore were awaiting shipment in September when the mine was visited. This ore is hauled to the railroad after McCarthy Creek freezes and snow for sledding has fallen.

The mine is equipped with an aerial tramway having a length of slightly more than 5,000 feet and a difference in elevation between the loading and landing stations of about 2,500 feet. Its capacity is 300 tons a day. A suitable site for the loading station was not found on the solid rock and one on the glacier was therefore chosen. Although built on an apparently insecure foundation it has given satisfaction.

Plans are under consideration for enlarging and bettering the equipment. It is proposed to build a road down McCarthy Creek to connect the mine with the railroad and to erect a hydroelectric plant and mill for treating the ore. A site for the power plant has been chosen on McCarthy Creek, 2 miles below the landing station. Water for milling ore can be obtained from Diamond Creek, half a mile above the camp. About 40 men were employed on the property in the summer of 1916.

DAN CREEK.

The Westover group is on Boulder Creek, a tributary of Dan Creek. It is the property of the Alaska United Exploration Co. and is one of four groups on Boulder and Dan creeks that belong

to the same company, which, although it is not a mining company, its business being to discover and sell prospects, has done considerable development work on Westover claim No. 1, on Golden Eagle claim No. 1, and on the Snow Bird groups.

The four Westover claims are on the east side of Boulder Creek, 2 miles above its mouth. They extend along the limestone-greenstone contact and cover an exceedingly rugged area. The Westover tunnel is at the base of a precipitous limestone cliff a few feet above the greenstone. It is 375 feet above the glacier from which Boulder Creek rises and 3,500 feet above Nizina River.

The ore is bornite, chalcocite, and chalcopyrite, the bornite predominating. The work thus far done shows that the ore is practically confined to two beds of limestone about 11 feet thick, which lie a few feet above the thin bed of shale that separates the limestone from the greenstone.

The original surface exposure showed a rudely wedge-shaped face of ore 35 feet long and about 10 feet high at its south end, where it consisted of massive bornite and chalcocite and where it was cut off abruptly from the limestone to the south. The north end, however, showed a gradation from bornite and chalcocite to silicified limestone. Underground work has revealed two principal ore bodies, one of which is exposed at the surface and extends in, as shown by the tunnel, for 35 feet; the other lies about 35 feet farther in from the boundary of the first body.

The copper minerals have replaced limestone along irregularly distributed fissures, which in the short time available for study could not be correlated with any system of faulting. Good evidence for faulting parallel to the bedding, however, was found, both along the shale bed between the limestone and greenstone and along bedding planes in the limestone. This faulting possibly accounts for the fact that the copper minerals are almost restricted to the two beds of limestone already mentioned, although the exact way in which they could be so restricted was not determined. However this may be, the ore is cut off sharply along the bedding planes.

The underground workings of the Westover, which, in addition to drifts and crosscuts, include three raises and four winzes, measure in all about 900 feet. The winzes range in depth from 5 to 60 feet. One of the raises was put up 73 feet.

About 100 feet above the Westover tunnel is a short tunnel and a shaft in a zone of crushed limestone that trends northeastward. Copper stains the limestone, but no ore body had been uncovered at the time of visit.

A considerable quantity of ore has been mined at the Westover and awaits shipment. Some of it was piled near the mouth of the tunnel and the rest was stored in crosscuts underground. A plan was

under consideration for shipping the ore mined and other ore blocked out, and a proposal was made to erect a small cable tram between the tunnel and the glacier moraine, where the ore could be loaded on sleds and hauled away in winter.

Exploratory work on the Snow Bird group is represented by two short tunnels run in copper-bearing greenstone. This group comprises four claims, and is on the west side of Boulder Creek valley, opposite the Westover tunnel. The tunnels are a few hundred feet below the limestone-greenstone contact, but the claims extend to the contact and one overlaps it. Chalcocite is the copper mineral. It is disseminated in small grains through an irregular-shaped mass of greenstone which has been leached by circulating water and has taken on a lighter color than the surrounding country rock. Probably this leached portion of the greenstone is in a zone of fracture, but, if so, the trend of the zone was not determined; neither was the extent of the mineralized rock determined, for much of the rock surface is covered by talus.

GOLD LODES IN THE TIEKEL DISTRICT.

GENERAL CONDITIONS.

The success of the Cliff mine at Valdez and the discovery of many smaller gold-bearing quartz veins in that vinicity in 1910 stimulated prospecting in the mountains along the Valdez-Fairbanks road and led to the finding of several similar gold-bearing veins, most of which are in the vicinity of Tiekel (Pl. X, p. 156). None of these veins have yet proved to be of value as gold producers, but development work has been done on some of them, which may be regarded as promising prospects. Among such prospects are the claims belonging to Fred Reis, about 3 miles south of Tiekel Road House; the Portland group, somewhat nearer Tiekel and high on the mountain on the west side of the valley; the two properties commonly known as the Ross and Meckem properties, on Boulder Creek; the Telluride and Quail groups, on Hurtle Creek; and the property of the Quartz Creek Gold Mining Co., near the head of Quartz Creek. In this connection also the gold placers of Fall Creek may be mentioned. All these properties except the first two were visited by the writer in July, 1916.

The rocks in the vicinity of Tiekel are slate and graywacke, which, however, are locally so much altered that the term "schist" describes them better, particularly the slate. They are closely folded and in general strike a little north of west. In places the slate or schist is highly siliceous, consisting of alternating bands of quartz and slate of the thickness of a knife blade. The slates and graywackes are cut by numerous light-colored dikes of diorite porphyry and contain stringers, lenses, and well-defined veins of quartz. Some of the

quartz veins are metalliferous and carry arsenopyrite, galena, and, in places, free gold. They are the veins that give promise of becoming gold producers.

The veins and the dikes of diorite porphyry were probably formed at the same time, although, so far as the writer knows, the dikes are not mineralized. Some of the small gold-bearing veins and lenses contain much gold, but, as a rule, the deposits are too small to make profitable mines. The problem of the district seems to be to find a vein large enough to mine or to find small veins spaced closely enough to pay for the dead work that must be done in mining them. This, however, may be said to be the problem of the prospector in most districts.

BOULDER CREEK.

Boulder Creek is a western tributary of Tiekel (Kanata) River, which it joins just north of the Tiekel Road House. Its two branches head in the same group of mountains in which the Valdez Glacier originates, are fed largely by melting snow and ice, and join at a point between 2 and 3 miles above its mouth. One of these branches comes from the south and the other, the larger branch, from the southwest. The valley of Boulder Creek is a hanging valley; its mouth is considerably higher than the floor of Tiekel Valley. A trail suitable for pack horses leads from Tiekel Valley around the canyon in which the lower part of the creek flows, and by a series of "switchbacks" gains the level of the old valley floor, from which either branch of the creek can be ascended without difficulty.

The Ross property is near the top of the ridge that stands between the south fork of Boulder Creek and Tiekel River. It is at an elevation of about 4,500 feet and is reached by a steep trail. The gold-bearing vein is in black siliceous slate, very much crumpled and sheared. A tunnel about 200 feet long has been driven on the vein but was closed at the time the property was visited. The vein is made up of quartz, arsenopyrite, and galena, and yielded very high assays in gold but is reported to be decidedly "bunchy."

The Meckem property is on the right branch of Boulder Creek, between 2 and 3 miles above the forks, and is easily accessible from the valley of Boulder Creek. The country rock is slate or schist and graywacke, striking east and dipping south. It is broken by joints that strike N. 20 W. and dip steeply to the west. These joints are parallel to a number of quartz veins and to a dike of diorite porphyry that is exposed about 100 feet east of the tunnel by which the property is being prospected. This tunnel is 150 feet above the creek and is about 75 feet long. It is driven in crumpled slate and graywacke. Above the tunnel are a number of lenticular branching quartz veins, the largest 8 feet thick in its thickest part. None of them was

traced on the surface for more than 100 feet. Most of these veins are composed of white and massive "bull quartz," but the smaller veins are more or less cavernous and are stained with iron oxide. Unoxidized parts of the veins show arsenopyrite and galena.

QUARTZ CREEK.

Quartz Creek is a tributary of Tonsina River. It heads in a low, divide 4 miles from the Valdez-Fairbanks road and flows northwestward for 10 miles, joining Tonsina River a short distance below the outlet of Tonsina Lake. Quartz Creek has two principal tributaries, Bear Creek and Rainbow Creek. Bear Creek, the larger of the two, enters it from the south about 3 miles above the mouth of Quartz Creek. Rainbow Creek comes in from the east a mile above Bear Creek. Nearly all of Quartz Creek south of Rainbow Creek is above timber line. A good trail, dry but rather steep, leads from the Valdez-Fairbanks road at mile 55 to a broad pass at the head of Quartz Creek.

The rocks exposed in the upper part of Quartz Creek valley are slate, schist, and graywacke. The schist is highly siliceous and much crumpled. Its principal exposure is in the ridge between upper Quartz Creek and Hurtle Creek. The higher parts of the mountains northeast of Quartz Creek below Rainbow Creek are made up of black slate, altered dioritic rocks, and light bluish-gray crystalline limestone. These rocks are probably older than those that are exposed farther up Quartz Creek and are believed to be, at least in part, of Carboniferous age.

Quartz Creek was the scene of considerable mining in 1898 and 1899. Placer gold was found in the stream gravels and a small settlement sprang up at the mouth of Bear Creek, where the old cabins still stand. The gold-bearing gravels, however, were quickly mined out, and the promise of a new camp was not realized.

The property of the Quartz Creek Gold Mining Co. is about 2 miles below the head of Quartz Creek on the ridge between Quartz and Hurtle creeks. It comprises 37 recorded claims and includes a mill site. A large number of mineralized quartz veins crop out. Some of these veins are here designated by numbers that have been assigned to them by the owners. The claims have been prospected by two tunnels—one 175 feet long, driven to cut vein No. 3, the other 65 feet long on vein No. 2. The longer tunnel is at an elevation of approximately 4,800 feet. It is driven in black crumbled schist and finely banded quartz and graywacke. These sedimentary rocks are cut by numerous dikes of diorite porphyry.

Vein No. 3 crops out at a vertical distance of a little more than 100 feet above the tunnel. It strikes N. 40° W. and dips steeply to the

east. It ranges from 1 to 2 feet in thickness and can be traced at least 400 feet. It is highly stained with iron oxide. The tunnel is not long enough to reach the vein, so that the character of the mineralization below the outcrop is not known. Vein No. 1, on the top of the ridge, contains arsenopyrite, galena, and chalcopyrite, or copper-bearing pyrite. The mineralization is typical of the district. Work on the tunnels had been discontinued at the time of visit, and the properties were attached for debts. Unfortunately the work done gives no better idea of the mineralization than can be gained from a study of the surface outcrops.

HURTLE CREEK.

Hurtle Creek is a small stream which flows into the upper or south end of Tonsina Lake. It is formed by the union of two branches, which come together about 2 miles from the lake. The west branch is about 5 miles long and flows almost due north, the east branch is somewhat longer and flows first north and then northwest. The valleys of both branches are above timber line, but spruce extends up the lower part of the creek to the forks. Both branches head against Boulder Creek, the east branch being separated from that stream by a comparatively low divide. Between the east branch and the upper part of Quartz Creek is a narrow ridge, which, at an elevation of about 4,500 feet, is crossed by a trail that leads to the Valdez-Fairbanks road at mile 55. The west branch rises in several small glaciers that lie in cirques at the south end of the valley.

The country rock of Hurtle Creek includes schist or slate and graywacke of the Valdez group, and is cut by numerous dikes of light-gray fine-grained diorite porphyry, whose courses are plainly seen on the steep rock walls of the valleys.

Two groups of claims have been staked on gold-bearing quartz veins on the east side of the west branch of Hurtle Creek, and at the time of visit, in July, 1916, were being developed by Messrs. Peter Layton and Charles Nelson, who, with one or two others, are the owners. One of these groups, the Quail group, is about 2 miles from the forks of Hurtle Creek, at an elevation of 4,000 feet, and includes 10 claims. The other is called the Telluride group, and includes 9 claims. It is higher on the mountain side than the Quail group and somewhat farther up the creek.

The veins of the Quail group have the better showing of ore and have been most developed. The country rock at the workings is gray slate or schist, which is much folded and sheared and cut by closely spaced northward trending joints that dip to the east. The deposits appear to lie in a fault zone of pressure and fracture. Some of the northward-trending fractures have been filled with mineralized quartz veins, and at least four veins have been uncovered. The

largest vein strikes north and dips 60° E. It ranges in thickness from 10 to 18 inches, and contains arsenopyrite, galena, and free gold in a gangue of quartz. Four feet below it is a parallel vein, 10 inches thick, and 1 foot above it is another vein, somewhat thinner. The fourth vein is 25 feet above the main vein and ranges in thickness from 1 foot to 15 inches. Its dip is a little steeper than that of the veins below. This vein contains the same minerals but a larger proportion of free gold. Open cuts on the veins have exposed them for about 300 feet along the strike. The veins appear to be cut off or offset on the north by a light-colored dike of diorite porphyry, which strikes east and dips south. This dike is exposed on the south side of a small creek about 500 feet north of the workings. In addition to the open cuts along the veins, a shaft, 10 feet deep, was sunk on the upper vein, and a tunnel was started below to crosscut the veins. This tunnel, which had been run 25 feet at the time the property was visited, will have to be driven 70 or 75 feet to reach the lower vein.

Nearly 3 tons of ore was packed out on horses to the Valdez-Fairbanks road in 1914 and shipped to the Tacoma smelter. At the time the property was visited an arrastre, to be driven by water power, had just been completed but had not been put into operation.

FALL CREEK.

Fall Creek, which is about 7 miles long, joins Tiekel River 2½ miles northeast of the Tiekel telegraph station. Its general course is northward. For most of its length it occupies a narrow glaciated valley, from which it issues through a deep canyon and flows for a mile across the level gravel-covered floor of the Tiekel. Most of the stream is below timber line. The country rock along it is slate and graywacke.

Fall Creek was prospected by the earliest gold seekers who ventured into this region in 1898 and 1899 and again during the gold-quartz excitement, about 1910, but its gravels did not prove profitable, and when the creek was visited in July, 1916, only three men were working along it.

A number of gold-bearing quartz veins have been staked in the valley, but only the placer gravels were receiving attention. Ten or a dozen placer claims have been staked. The two claims on which work was being done were visited, yet at both only preparatory work was in progress; no mining had yet been done.

Messrs. Nick Meckem and Fred Reis were preparing to sluice gravel on the upper end of claim No. 5, which is in the canyon at a place where the gravel deposits are shallow and are confined to points inside the bends of the stream. The gravel-covered point where work had been started measures only about 50 by 100 feet and the deposit

is 6 to 8 feet deep. A channel had been made on the east side of the creek next to the canyon wall and sluice boxes were being set up to wash the 2 feet of gravel that remained after the boulders has been cleared away. The gravel is slate and graywacke and includes a large number of boulders of graywacke, many of which have to be broken by powder in order to get them out of the cut. The gold is not distributed through the gravel but is found only on bedrock, the upper few inches of which have to be taken up. It is heavy and considerably worn.

On claim No. 10 Jack Reynolds was mining the low bench that borders the creek. The channel is wider here than below, for the claim is above the canyon, in the open valley, at an elevation of only about 2,400 feet, well below timber line. Here, along the east side of a bend in the creek, there is a low bench of gravel, 6 to 7 feet thick, through which Mr. Reynolds had run a line of sluice boxes about 200 feet long. The gravel consists largely of boulders of graywacke, many of which have to be broken by powder, and when this and other coarse material had been taken out about 2 feet of finer material remained that could be shoveled into the boxes. The gold here, like that mined farther down the creek, is heavy and rounded and is found only on the bedrock. Mr. Reynolds reported that with a rocker he took $21 from a bar in five hours, but that he did not regard the bar as pay ground.

MINING ON PRINCE WILLIAM SOUND.

By BERTRAND L. JOHNSON.

GENERAL FEATURES.

The mineralization of the closely folded rock beds that border Prince William Sound introduced into them a considerable variety of minerals, among which were gold, silver, chalcopyrite, chalmersite, pyrite, pyrrhotite, arsenopyrite, galena, sphalerite, stibnite, quartz, epidote, albite, chlorite, calcite, and ankerite. The valuable metals of the ores of this region are copper, gold, and silver. The gold thus far observed is native. The copper occurs chiefly as chalcopyrite, but another copper-iron sulphide (chalmersite), containing about 23½ per cent of copper, has been recognized at prospects on Landlocked Bay and on Knight Island. Silver has been noted as an alloy of the native gold and is also associated with some of the copper ores, but in what combinations is not known.

The ore deposits of this region may be broadly grouped into two classes—copper deposits and gold-bearing quartz lodes. The mineral associations in both gold and copper deposits are in general the same, the dominant characteristics of the deposits depending on the relative abundance of the different minerals. The copper mines produce large quantities of gold or silver, or both, and the gold-quartz lodes contain small quantities of chalcopyrite. The gold-quartz lodes occur in the folded and broken graywackes and argillites; the sulphide ores are restricted to the sheared slates, graywackes, limestones, and greenstones. The gold districts lie in a belt that parallels the shore of the sound and nearly surrounds the belt which contains the copper districts, to the south.

The gold-quartz ores are free-milling. They are crushed locally in small stamp or roller mills and the concentrates are shipped to the smelter at Tacoma, Wash. The copper ores are base and require smelting, with or without previous concentration. At one plant a flotation process is in operation. No local smelters being available, the copper ores are shipped to smelters at Tacoma, Wash., and Anyox, British Columbia, where their copper, gold, and silver content is recovered.

The productive mines on Prince William Sound in 1916, so far as known, included 8 copper mines and 10 gold mines. As usual, a

much larger quantity of copper ore than of gold quartz was mined and treated, and the total value of the metals obtained from the copper ores was several times that of the metals from the gold quartz ores. The value of the total mineral output of the Prince William Sound region in 1916 was $2,975,200, compared with $1,340,996 in 1915.

COPPER MINING.

GENERAL CONDITIONS.

Copper mining in the Prince William Sound region showed a greater activity in 1916 than in the preceding year, and this activity would probably have been much more noticeable had it been possible for the owners of small copper mines to take advantage of the high price of copper and to sell their ore on more favorable terms than were obtainable at the customs smelters, which throughout the year were operating to their full capacity. Both of the regular producers, the Kennecott Copper Corporation, at Latouche, and the Ellamar Mining Co., at Ellamar, made large shipments as usual. The Granby, Consolidated Mining, Smelting & Power Co. (Ltd.), owner of the Midas mine, in the Valdez district; the Alaska Mines Corporation, controlling the Schlosser property, on Port Fidalgo; the Dickey Copper Co., on Port Fidalgo; and the Fidalgo Mining Co., on Port Fidalgo, also shipped considerable ore. Small shipments were made from the Buckeye group, on Landlocked Bay, and from the Copper Coin group, on Knight Island. The Threeman Mining Co., on Landlocked Bay, which had shipped much ore in previous years, made no shipments in 1916. Development work was done on some of the nonproducing properties, and assessment work is reported on many others. Crude ore was shipped from all the producing properties, and in addition copper-bearing flotation concentrates were shipped from the Beatson Bonanza mine, on Latouche Island. The copper-bearing mineral in all the ore was chalcopyrite. Much of the copper ore mined also carries either gold or silver, or both.

A largely increased quantity of copper ore was mined on Prince William Sound in 1916, and the production of copper, gold, and silver from the copper ores was for each metal much in excess of that of the preceding year. The future position of the Prince William Sound region as an important copper producer appears to depend on the successful treatment of the lower-grade copper ores by concentration or by a marked lowering of the mining or metallurgic costs through some radical change in methods. The completion and successful operation of the flotation plant at the Beatson Bonanza mine of the Kennecott Copper Corporation, on Latouche Island, marks an important step in the progress of this region as a copper producer.

WORK DONE DURING THE YEAR.

LATOUCHE AND KNIGHT ISLANDS.

The mining developments on Latouche and Knight islands are discussed in detail elsewhere in this volume.

UNAKWIK INLET, WELLS BAY, LONG BAY, AND GLACIER ISLAND.

Seven men are said to have been at work on the Glendenning property, on Cedar Bay, during the summer of 1916, and 400 feet of tunnel was driven. A crosscut tunnel is also reported to have been started on the property of the Wells Bay Gold & Copper Mining Co. near by. Work was in progress during the summer on the Wagner property, on Siwash Bay, a western arm of Unakwik Inlet, and on the Anderson property, on Unakwik Inlet. Assessment work is reported on a group of claims on Glacier Bay.

VALDEZ DISTRICT.

A considerable amount of underground development work was done at the Midas mine of the Granby Consolidated Mining, Smelting & Power Co. (Ltd.), on Solomon Gulch, during 1916. The main tunnel has been extended to a length of 735 feet. A 200-horsepower Diesel engine was installed at the mine and furnished power to operate a 160-horsepower compressor and also a small generator. Arrangements were being made for hoisting equipment, and it was expected that sinking would commence early in 1917. Regular shipments of ore to the company's smelter at Anyox, British Columbia, were commenced in August, 1916, and continued during the remainder of the year.

The Peabody Alaska Copper Corporation, controlling the old Addison Powell property, on Sulphide Gulch about 4 miles from its junction with Lowe River, is reported to have done annual assessment work, consisting of open cuts, stripping, and a few feet of tunneling.

ELLAMAR DISTRICT.

The plant of the Ellamar Mining Co., at Ellamar, was operated for 355 days, working two shifts a day, and a large quantity of ore was mined and shipped. The underground work was largely between the 100 and 200 foot levels, and some of the siliceous ore between the surface and the 100-foot level west of the main ore shoot has been removed. A large waste open cut has been made on the slate hill southeast of the mine. This is tapped from the 100-foot level, and the slate is used for filling. The water level in the mine has been lowered to the 500-foot level. Some diamond drilling was done on the claims owned by the company. Surface improvements made during the year

include the construction of a warehouse on the dock, a new change house for the men, an addition to the bunkhouse providing for 12 men, and an addition to the cookhouse. A maximum force of 100 men was employed on the property during the year. The force during the last seven months of the year averaged about 90 men.

Although the Threeman Mining Co., on Landlocked Bay, made no shipments during the year, some underground development work was done on the Keystone claim. A raise was put through between the new third level and the second level, and some stoping was done on the third, fourth, and fifth levels. One man was at work on the property during the spring, but later in the season the force was increased to 10 men.

The Hemple Copper Mining Co., on Landlocked Bay, reports the driving of 150 feet of tunnel in 1916.

The property of the Standard Copper Mines Co., on Landlocked Bay, was leased for four years by the Alaska Standard Copper Mining Co. Work, consisting of repairs to buildings, dock, and equipment, is said to have commenced November 22, 1916.

A small lot of ore was shipped to the Tacoma smelter from the Buckeye group, near the head of Landlocked Bay, in the spring of 1916. Two men were at work on the property during the spring and one man during the summer.

Only assessment work is reported on the property of the Landlocked Bay Copper Mining Co.

PORT FIDALGO.

Development work was in progress in 1916 at all three of the copper mines on Port Fidalgo. The Fidalgo Mining Co. shipped a few hundred tons of ore during the year, drove about 250 feet of tunnels, and completed the installation of a small water-power plant. This plant was not finished till late in the season and was in operation only about a month. Water under a head of 400 feet drives a 36-inch Pelton wheel belted to a single-stage compressor with a capacity of 385 cubic feet a minute, which operates two jack hammers and one stoper. A good cropping of ore is reported to have been found during the year about 300 feet east of the old workings.

The Alaska Mines Corporation operated the old Schlosser property continuously throughout the year, with an average crew of 17 men and a maximum of 27 men. A new wharf and several new buildings were erected on the property, and considerable underground work was done. A new tunnel driven about 140 feet below the upper terminal of the aerial tram encountered ore. Ore was also mined from the upper levels. The total amount of underground work done during 1916 is said to have consisted of 350 feet of drifting and about 300 feet of raises. The first shipment of ore was made in February,

1916, and several other shipments were made later in the year. No shipments were made in 1915.

The Dickey Copper Co., owners of the Mason and Gleason claims, on Irish Cove, employed from 3 to 15 men at different times during 1916 and did between 500 and 600 feet of underground work. The wharf and ore bunkers on Irish Cove were completed early in the year. A shipment of several hundred tons of ore was made in the spring. Operations at the mine were discontinued for the year in October.

GOLD MINING.

GENERAL CONDITIONS.

The gold produced in the Prince William Sound region, other than that obtained from the gold-bearing copper ores, comes from both gold-quartz lodes and gold placers. The placer deposits, because of the recent intense glaciation of the region, are few, small, and irregularly distributed. They are worked only intermittently, on a very small scale, and contribute little to the gold production. The producing gold-quartz lodes are in the Port Wells and Port Valdez districts. The Granite mine, on Port Wells, and the Ramsay-Rutherford mine, in the Port Valdez district, are the largest producers.

WORK DONE DURING THE YEAR.

PORT WELLS DISTRICT.

The geology and economic features of the gold-quartz deposits of the Port Wells district, together with the developments up to and including 1915, have been described in recent reports.[1] The Granite mine continues to be the most productive property in the district. Small test shipments were made during the year from the Reagan group, on Culross Island, and from the Banner group, on Bettles Bay. Underground development and assessment work was done on many properties in the district, a few new lode discoveries are reported, and new milling plants were in process of erection on three propertes. Ocean-going steamers continued their visits to Port Wells, and a regular mail and passenger service was maintained between Valdez and Port Wells points. A new post office has been established at the Granite mine, and the one at Golden has been discontinued.

At the Granite mine underground development was in progress throughout the year and over 2,000 feet of workings, consisting of drifts on the several levels and a few stopes, are reported to have

[1] Johnson, B. L., The Port Wells gold lode district: U. S. Geol. Survey Bull. 592, pp. 195–236, 1914; Mining on Prince William Sound: U. S. Geol. Survey Bull. 622, pp. 131–139, 1915; Mining on Prince William Sound: U. S. Geol. Survey Bull. 642, pp. 137–145, 1916.

been opened. A new intersecting vein was discovered on the hoist level and tapped on the 50-foot level by a short crosscut. The mill was operated from January 1 to June 1, both the 10 stamps and the Lane mill being used. Milling operations ceased temporarily on June 1 and were not resumed until October 1, when only the 10 stamps were put into commission. A maximum of 65 men were employed on the property during the spring; two shifts were worked daily in the mine and three shifts in the mill. During the cessation of milling operations in the summer the working force is reported to have been cut to about 45 men. Early in October 50 men were at work on the property.

The Thomas-Culross Mining Co., on Culross Island, started the erection of a milling plant on the south side of Thomas Bay, near the head of the bay. The mill building, in process of erection in October, 1916, is about 1,350 feet from the mouth of the mine tunnel, with which it is to be connected with a ground tram, also partly completed at that time. The mill equipment, including a 10-foot Lane mill, Pelton waterwheel, and Samson jaw crusher, was on the property. Five men were employed in the construction of the plant.

Very little underground work was done on the vein on this property during the year, one man being at work for 34 days. A crosscut tunnel about 150 feet long taps the vein at the inner end of the tunnel and a drift follows the lead from this point for about 250 feet. Two shafts, 10 feet and 28 feet deep, have been sunk on the outcrop of the ore body. A new shaft house was erected during the year to take the place of the one demolished by the storms of the preceding winter.

A test shipment of gold-bearing quartz was made to Seattle from the Reagan group, on Culross Island, in February, but no work other than the annual assessment work was done on the property during the year.

A mineralized porphyry dike is reported to cut at a slight angle the bedding of the slate and graywacke series on the Golden Giant group, on the north side of Passage Canal. This property lies east of the foot of Billings Glacier, about 1 mile north of tidewater. The dike is said to have a width of 2 to 5½ feet and to be traceable for several thousand feet. The dike contains numerous quartz stringers, of various thicknesses up to 8 inches, which carry free gold, sphalerite, and galena.

Only assessment work was done on the Lone Star group, the Homestake, and the property of Dunklee & Reilly, on Pigot Bay. On the Lone Star the underground development work is said to consist of a 100-foot crosscut and a 50-foot drift on the lead.

On Bettles Bay a 250-foot tunnel was driven on a mineralized dike on the Banner group, near the entrance of the bay, at an altitude

of about 148 feet. It exposes a shattered acidic dike, which ranges in width from 1 to 8 feet and averages 4 feet. The dike is reported to be traceable across the ridge from Bettles Bay to Hummer Bay, where it is said to crop out about 2,000 feet above the head of the bay. A small dike about 1 foot in width branches from the main dike in the tunnel and extends southward a few feet east of the main dike. The shattered dike is cut by numerous quartz stringers that contain gold, arsenopyrite, galena, and sphalerite. Two men were employed on the property during the winter of 1915–16, and two additional men were put on in the spring. No work was in progress during July and August, but in October work had been resumed with a force of five men. A test shipment of ore was made during the year.

Assessment work only was done on the Yakima claim, on Bettles Bay. A total of 65 feet of tunnel has been driven on the property.

On the Mineral King property, better known as the Hermann-Eaton, about 75 feet was driven on a proposed 500-foot adit which will tap the vein at a depth of 230 feet. A 10-stamp mill, five Monarch concentrating tables, waterwheels, and an air compressor were brought from the Hope district, on Turnagain Arm, and placed on the property but were not erected. About 900 feet of hydraulic pipe was installed. Work was suspended on the property about December 10, with the exception of two men hand drilling.

A galena-bearing vein was located during the summer in the hills about 1½ miles north of the Mineral King.

Four men are reported to have driven a 200-foot tunnel on a property between Hobo and Bettles bays.

The Sweepstake Mining Co. is said to have erected a 2-stamp mill on its property on Harriman Fiord. Some work is reported on the property of the Homestake Mining Co.

On Barry Arm a quartz vein is reported to have been discovered about 5 miles up from the mouth of the arm, a mile from the shore.

A 120-foot tunnel was driven during the year on the Osceola vein, on College Fiord.

Two to four men were at work during 1916 on the Consolidated claim, on Avery River, and 120 feet of tunnel is said to have been driven on the lead. On the Nugget, at Golden, 45 feet of tunnel was driven. On the Arrow Head group (H. C. Johnson and George Wagner, locators and owners), at Golden, a crosscut tunnel struck an ore vein 100 feet from the mouth of the tunnel. This vein was followed for 45 feet. In addition to this work drifts were run in both directions, a total distance of 35 feet, on a vein that crosscuts this long tunnel. Only assessment work is known to have been done on the other properties in the vicinity of Golden.

PORT VALDEZ DISTRICT.

The economic geology of the gold deposits of the Port Valdez district, with the mining developments up to and including 1915, have been described in recent reports,[1] and a detailed report on this district is now in preparation.

The producing properties in 1916 in the Port Valdez district included the Ramsay-Rutherford, Cliff, and Gold King, and those of the Valdez Gold Co. and the Mineral Creek Development Co. Small test shipments were also made from the Alice and Rambler properties. Development work was in progress on a few other properties, and the annual assessment was done on many others.

Underground development work was in progress on the claims of the Ramsay-Rutherford Gold Mining Co. throughout the year. Work was done on the 100, 150, 225, and 300 foot levels, and stoping was in progress between all these levels. Two shifts were worked daily in the mine. Milling operations continued from the previous year till the later part of January, when the water supply froze. The mill started again late in May and was reported to have been in operation the rest of the year. Three shifts were worked daily in the mill. An average of 20 men were employed on the property throughout the year.

On the property of the Valdez Mining Co., on the south side of the Valdez Glacier, 100 feet of tunnel was driven by three men.

Two men, at work during part of the summer on the Pinochle claim, drifted both ways on the vein in the lower tunnel, a total distance of about 40 feet.

The Mineral Creek Development Co. is the present owner of the Hercules and Millionaire claims, on Mineral Creek. Six men were at work on these claims from March to about the end of September. A 200-foot crosscut was driven on the Hercules claim and drifts were run on the vein for 40 to 50 feet. A small amount of work was also done on the Millionaire claim. A mill, formerly on the Big Four property, near by, was erected on property of the Mineral Creek Development Co. and was operated for about a month and a half. Surface improvements on these claims during the year were limited to the erection of the mill building. Assessment work only is said to have been done on the Little Giant, Rose, Big Four, and other properties on Mineral Creek.

The Cube Mining Co., owner of a bond on the Three-in-One claims, report the driving of 600 feet of tunnel on the vein and the installa-

[1] Brooks, A. H., Gold deposits near Valdez: U. S. Geol. Survey Bull. 520, pp. 108–130, 1912. Johnson, B. L., Mining on Prince William Sound; U. S. Geol. Survey Bull. 592, pp. 237–243, 1914; Mining on Prince William Sound: U. S. Geol. Survey Bull. 622, pp. 131–139, 1915; The gold and copper deposits of the Port Valdez district: U. S. Geol. Survey Bull. 622, pp. 140–188, 1915; Mining on Prince William Sound: U. S. Geol. Survey Bull. 642, pp. 137–145, 1916.

tion of an amalgamation and concentration plant, in which the crushing unit is a Hardinge conical mill. During the early part of the year only a few men were at work on the property, but the force was gradually increased, and in October 15 men were employed. Drifting is reported on both levels in the mine.

Work was started on the Black Diamond group about the middle of May. An upper tunnel at an elevation of about 700 feet was started on the lead and driven a distance of 140 feet during the year. Considerable open-cut work and stripping of the vein was also done. An upper camp of four buildings was completed during the year. From one to three men were employed in the development work.

Some underground development work was done on the McCallum lode claims near the head of Gold Creek.

An average of 14 to 18 men were employed at the Cliff mine during the year. The dock was put in good condition. Underground development work was continuously in progress, but milling operations were intermittent. Three raises were put through from the 100-foot level to a prospect tunnel about 200 feet above the beach, a raise was started from that tunnel toward the next level, and a little stoping was done above the prospect tunnel. A small winze is also reported to have been sunk 40 feet below the level of the prospect tunnel, and drifts were extended each way on the vein from the bottom of the winze. A little ore was also stoped out between the 100-foot and 200-foot levels.

On the property of the Sea Coast Mining Co., on Shoup Bay, a mill building was erected at the mouth of Uno Creek, and a 10-stamp mill, jaw crusher, and two tables were installed. Three small cottages were erected near by. The building to house the hydroelectric power plant on Uno Creek was also completed, but at the time of visit all the machinery for this plant had not yet arrived on the ground. The aerial tram connecting the mine and mill was nearly completed. At the mine about 400 feet of drifting was said to have been done on the vein. An average of 20 men were at work on the property during the year.

Assessment work is reported on the Alice claim, and a small shipment of ore was made from the surface croppings. The tunnel on the Blue Bird claim, on the south side of the mouth of Shoup Bay, was extended 20 feet. On the Guthrie-Belloli claims, in Uno Basin, two men drove a new lower crosscut tunnel 90 feet in length, cutting the vein at the inner end of the tunnel. Drifts were then run about 25 feet each way along the vein. Both tunnels on the Gold Standard were extended a few feet. One man was at work on the Nymond claims during part of the summer. On the Bald Mountain group, on Shoup Glacier, between 30 and 35 feet of drifting was done in the main tunnel.

The claims of the Valdez Gold Co. (formerly known as the Cameron Johnson Gold Mining Co.) were worked during the summer with a force of 12 to 15 men. Several hundred feet of work is reported to have been done on the upper showings. The mill was run only a very short time, and only a few tons of ore was milled.

On the Tuscarora claim assessment and development work is reported to have been in progress from June 15 to the end of the year, and 45 feet of underground work was completed.

On the Rambler vein 150 feet of tunnel was driven and a shipment of ore was made for a mill test.

Assessment work is reported on the property of the Thompson-Ford Mining Co. and on the Bunkerhill and Minnie claims.

The Gold King claims, on Columbia Glacier, were operated during the year. Two men were engaged in development work during the winter, but from June 1 to September 1 this force was increased to six or eight men. No changes in the plant were made, and no new construction work was done. The mill was operated during most of the summer. The underground development work done during the year is reported to have included 230 feet of drifts and a 68-foot raise, with stopes along all of the raise.

COPPER DEPOSITS OF THE LATOUCHE AND KNIGHT ISLAND DISTRICTS, PRINCE WILLIAM SOUND.

By BERTRAND L. JOHNSON.

INTRODUCTION.

In the present preliminary report the distribution, geologic relations, and characteristics of the copper deposits of the Latouche and Knight Island districts will be briefly described. A more complete and detailed report on these districts is in preparation.

The earliest recorded reference to either of these districts is that of Cook,[1] who in May, 1778, after a brief exploration of Prince William Sound, left those waters through Montague Strait. Portlock[2] in the spring of 1787 explored the east side of Latouche Island and part of Knight Island Passage. In June, 1794, Joseph Whidbey, of Vancouver's expedition,[3] crossed from Montague Island direct to Cape Puget, on the mainland of Kenai Peninsula, passing on the seaward side of Latouche and adjoining islands, and after traversing the shores of Port Bainbridge went through Bainbridge Passage on his way northward.

Schrader[4] visited Latouche Island while studying the geology of Prince William Sound in 1898, and again, in company with A. C. Spencer, in 1900. In 1905 Grant[5] studied these districts in greater detail. Grant and Higgins[6] made additional observations in 1908 and 1909.

[1] Cook, James, A voyage to the Pacific Ocean [etc.] in the years 1776–1778, 3 vols., maps, London, 1784–1785. (See vol. 2, p. 364, 1785.)

[2] Portlock, Nathaniel, A voyage round the world [etc.] performed in 1785, 1786, 1787, and 1788, pp. 210–211, London, 1789.

[3] Vancouver, George, Voyage of discovery to the North Pacific Ocean [etc.] in the years 1790–1795, vol. 3, pp. 176–178, maps, London, 1798; new edition with corrections, vol. 5, pp. 300–304, 1801.

[4] Schrader, F. C., A reconnaissance of a part of Prince William Sound and the Copper River district, Alaska, in 1898: U. S. Geol. Survey Twentieth Ann. Rept., pt. 7, pp. 354, 419–420, 1900.

Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, Alaska, pp. 15, 27, 37, 89: U. S. Geol. Survey Special Pub., 1901.

[5] Grant, U. S., Copper and other mineral resources of Prince William Sound; U. S. Geol. Survey Bull. 284, p. 82, 1906.

[6] Grant, U. S., and Higgins, D. F., Copper mining and prospecting on Prince William Sound: U. S. Geol. Survey Bull. 379, pp. 87–93, 1909. Reconnaissance of the geology and mineral resources of Prince William Sound, Alaska: U .S. Geol. Survey Bull. 443, 1910. Grant, U. S., Copper deposits of Prince William Sound, Alaska: Min. and Sci. Press, vol. 100, pp. 63–64, 1910; Mining and prospecting on Prince William Sound in 1909: U. S. Geol. Survey Bull. 442, pp. 164–165, 1910.

A detailed description of the Beatson-Bonanza mine, on Latouche Island, has been given by Lincoln.[1] Notes on the mining developments of the district have been given by Moffit[2] and Johnson.[3]

The field work on which this report is based began June 19, 1916, and ended October 5, 1916. The successful completion of the work of the season was greatly facilitated by the use of the launch *Prospector*, of Cordova, in charge of Capt. George E. Scott. The conclusions presented in the text, being the results of a preliminary study of the data collected during the field season, are tentative and are subject to revision, if needed, in the more complete report.

The writer's thanks for information furnished and assistance rendered are here extended to the officials of the Kennecott Copper Corporation, at Latouche, to Mr. Hancock, at Horseshoe Bay, and to Messrs. George E. Scott, W. B. Harris, J. A. Wilson, Teening Carlson, Harry Moore, and many others.

GEOGRAPHY.

Situation.—The Latouche and Knight Island copper districts lie at the west entrance to Prince William Sound, on a northwestward-trending group of mountainous islands, of which Latouche, Knight, Elrington, Hoodoo, and Bainbridge islands are the principal members. (See Pl. XII.)

Relief.—The relief of the districts is moderately strong. The mountain summits range from 1,000 feet to a little over 3,000 feet above sea level, but only on Knight, Bainbridge, and Latouche islands do their altitudes exceed 2,000 feet. Knight Island is the most rugged of the group, and its mountains are much the highest in the districts, one peak, Mount Marion, in the southern part of the island, rising to an altitude of 3,280 feet. Along the east side of Bainbridge Island the maximum height reached is 2,351 feet, and the higher summits of the cirque-carved backbone of Latouche Island stand at 2,018 to 2,255 feet.

Glaciation.—The entire region has been intensely glaciated, but the remnants of the ice sheet which once covered these islands are few, small, and of the alpine type, none reaching tidewater. They are observed only on Knight Island. Many large glaciers, however, are present on the mainland of Kenai Peninsula, just west of this group of islands. Some of these are tidal glaciers and discharge icebergs, which, in summer, may frequently be seen floating among these islands.

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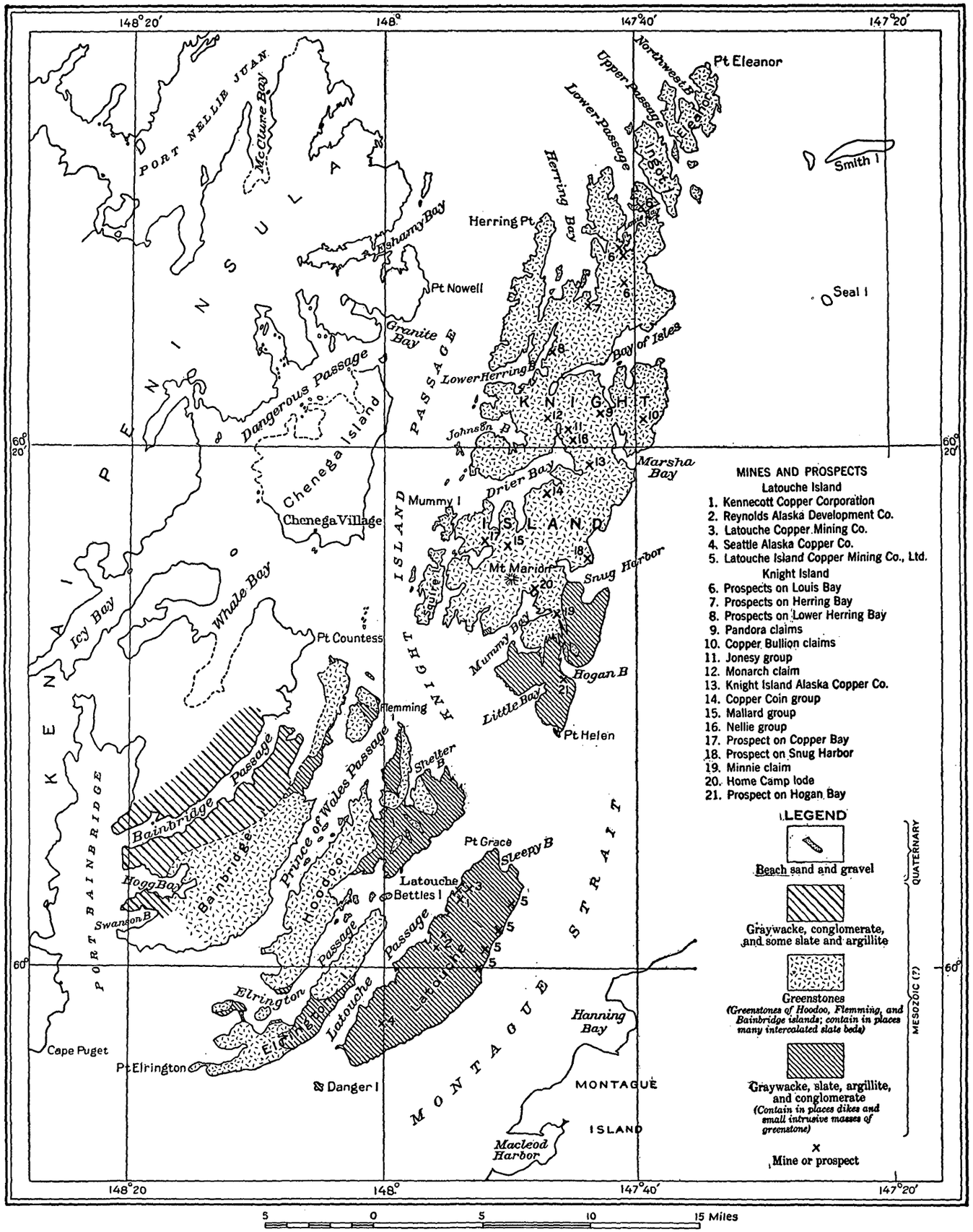
[1] Lincoln, F. C., The Big Bonanza copper mine, Latouche Island, Alaska: Econ. Geology, vol. 4, pp. 201–213, 1909.

[2] Moffit, F. H., Notes on copper prospects of Prince William Sound: U. S. Geol. Survey Bull. 345, pp. 176, 178, 1908.

[3] Johnson, B. L., Mining on Prince William Sound: U. S. Geol. Survey Bull. 592, p. 243, 1914; Bull. 622, pp. 132–133, 1915; Bull. 642, p. 139, 1916.



GEOLOGIC SKETCH MAP OF THE LATOUCHE AND KNIGHT ISLAND DISTRICTS.

Drainage.—The surface waters of these islands flow directly to the numerous passages between the islands or to the many small bays indenting their shores. The streams are short and drain small areas. Most of the streams are less than a mile in length, and the longest stream has a length of but 2⅓ miles.

On some of the streams small water powers could be developed, and on Latouche Island small power plants are in operation at two properties.

Climate.—The Latouche and Knight Island districts lie within the Pacific coast climatic province, the climate of which is essentially temperate and humid, being characterized by heavy precipitation and a comparatively high mean annual temperature.

The average annual precipitation on Prince William Sound, as shown by records kept at Valdez and Cordova, ranges from about 74 inches at Valdez to about 132 inches at Cordova. In 1912 the precipitation at Cordova was 191 inches, but the rainfall in that year was exceptionally heavy. Records kept at Latouche from September 1, 1915, to September 1, 1916, by Mr. B. H. Dow, of the Kennecott Copper Corporation, showed rainfall for those twelve months of 142.26 inches. The average mean annual temperature at that place for the same period, computed from readings made at 8 a. m. daily, was 38° F. The average temperature for the three summer months was about 51° F., and the average for the three winter months about 27° F.

Timber.—The Latouche and Knight Island districts are included within the Chugach National Forest and are abundantly timbered. Timber line ranges from 1,000 to 1,500 feet above sea level. Most of the smaller islands are completely covered with timber, and many of the larger islands have only a few peaks or ridges rising slightly above timber line. The largest untimbered areas are on Knight Island. The forest trees include spruce, western hemlock, mountain hemlock, and alder. Coniferous trees, 4 to 5 feet in diameter, are occasionally found, but the average diameter of the larger trees is probably from 1 to 2½ feet. Timber suitable for most purposes can be cut near most of the mines and prospects, but the better grades of lumber must be brought from Seattle. Dressed lumber can also be purchased at Valdez.

Population and settlements.—The population of these districts is dependent upon the mining industry, and the existing settlements are at or near mines or prospects. Latouche, the largest settlement, with a population of about 400, is on the west coast of Latouche Island near its north end. This settlement has been built up close to the Beatson-Bonanza mine. Most of the supplies necessary for prospecting are obtainable here at the mine store of the Kennecott Copper

Corporation. Gasoline, however, was obtainable in 1916 only in 10-gallon lots, at 45 cents a gallon.

Several houses have been built on Horseshoe Bay on the west side of Latouche Island near the prospects of the Reynolds Alaska Development Co., and in 1916, while development work was in progress, about 15 persons were living at that place.

Latouche serves as a distributing point for much of these districts, but a considerable number of the Knight Island property owners use either Valdez or Ellamar as a supply point. Public wharves are available at Valdez and Cordova for the transshipment of machinery and supplies from the ocean-going steamers arriving from the States to the smaller boats that are available for trips to the prospects. There are no public wharves in these districts. The wharf at Latouche used by the regular steamers is the property of the Kennecott Copper Corporation. Hotel accommodations are available only at Valdez and Cordova, although quarters for visiting engineers have been furnished at the mines.

Transportation.—Transportation facilities to and from points in the United States are fairly good. Latouche, the only port of call within these districts, is on the regular routes of travel for ocean-going steamers of two lines running to southwestern Alaska points. There are about nine passenger boats each way a month in the summer and about five a month in the winter. The passenger boats carry freight, and there are also several boats engaged exclusively in freight transportation. Passenger rates in 1916 were the same on both lines for all Prince William Sound points, and were as follows: First class, upper deck, $50; first class, lower deck, $47.50; steerage, $30. Freight charges from Seattle to Prince William Sound point in 1916 ranged from $3 to $45 a ton according to classification. First-class passenger fare on the large boats between Valdez and Latouche is $5 each way; steerage, $3 each way.

Local travel is entirely by small boats. There is no regular service, but gasoline launches are usually available at Latouche and are apparently more abundant and more readily obtainable at Valdez.

As water routes are used for practically all transportation between mining camps and their supply points and the conditions for water travel are so favorable and those for land travel so difficult, little has been done to construct or improve roads or trails between camps, and those already constructed are restricted to trails from the shore camps to the mines and prospects. A United States post office has been established at Latouche for several years. In the summer of 1916 a wireless plant, reported to be of sufficient power to communicate with stations at Kodiak and Cape Whitshed and approaching steamers was erected at Latouche.

GEOLOGY.

PRE-QUATERNARY ROCKS.

The pre-Quaternary rocks of these districts include both sedimentary and igneous types. The sedimentary rocks are all regionally metamorphosed and may be segregated into two distinct groups—(1) the graywackes, slates, argillites, and conglomerates of Latouche, Knight, Flemming, Hoodoo, and Elrington islands and of the eastern and southern parts of Bainbridge Island and (2) the massive graywackes of Kenai Peninsula and the western part of Bainbridge Island. All the igneous rocks of both districts are in this preliminary report grouped under the general term "greenstones."

GRAYWACKE, SLATE, ARGILLITE, AND CONGLOMERATE OF LATOUCHE, KNIGHT, HOODOO, FLEMMING, AND ELRINGTON ISLANDS.

The sedimentary rocks of Latouche, Danger, Knight, Hoodoo, Flemming, and Elrington islands and of the eastern and southern parts of Bainbridge Island consist chiefly of graywacke, slate, argillite, conglomerate, and a very small amount of limestone. It is probable that this group will eventually be separated into a considerable number of formations. At present several lithologic units are recognized and will be described briefly.

The oldest unit, which crops out in a wide belt on Discovery Point, on the south side of Snug Harbor, Knight Island, is composed of fine-grained dark-gray, slightly calcareous slate, with thin layers of coarser-grained lighter-gray slate rarely exceeding 2½ inches in thickness and spaced from 1 inch to 9 inches apart. These thin layers are in places intricately folded. The slates also contain small brown-weathering, slightly calcareous nodules, some of which attain a thickness of about 15 inches, and a few thin beds of limestone, including one 6 inches thick. The slates are thinly cleavable in places.

Overlying these slates is a thick succession of thin-bedded graywacke, which covers most of the drainage area of Hogan Bay and the eastern half of Latouche Island. The thickness of the individual graywacke beds ranges from 1 foot to 30 feet, but the average bed measures 10 feet or less. On Knight Island this formation contains, near the lower contact, a few layers, 5 to 50 feet in thickness, of thin-bedded argillite resembling the slate on Discovery Point, but slightly more siliceous. The graywacke is rather light colored. The argillitic beds are dark gray and are in places much iron stained. The bedding in the graywacke is sharply defined and clean cut, individual beds separating readily from each other.

On Latouche Island a thick mass of slate and argillite lies above the bedded graywacke. This is overlain by another graywacke series, above which is a group of alternating slate, graywacke, and argillite, with some chert and limestone. A band of black slate of considerable width passes through Latouche. Conglomerate crops out in a narrow belt at Latouche and on Little, Horseshoe, and Pleasant bays. The conglomerate contains numerous small, well-rounded pebbles of both sedimentary and igneous rocks, of which quartz, quartzite, chert, argillite, slate, light-colored fine-grained granitic rocks, and both light and dark colored porphyries are the most abundant, also many fragments of slate and argillite. Above the conglomerate beds is more graywacke, overlain by a mass of slate carrying but little graywacke, which forms the west coast of Latouche Island from Horseshoe Bay to Pleasant Bay.

The sedimentary rocks on Hoodoo, Flemming, and Elrington islands and the east side of Bainbridge Island are largely slate, with minor amounts of graywacke and conglomerate. The conglomerate is most prominent on the northeast shore of Hoodoo Island near Bishop Rock but occurs also on Elrington Island near the south end of Elrington Passage and on Knight Island between Mummy and Little bays. It is similar to those found on Latouche Island.

Fossils have been found within this group at several localities, but with one exception they have not proved of diagnostic value. A comatulid crinoid was found in the slates on the west side of Hoodoo Island. J. B. Reeside has reported on this specimen as follows:

16 AJ 73 (10014), Hoodoo Island: Centrodorsal and two arms of a comatulid crinoid referred by A. H. Clark to an undescribed genus of the subfamily Bathymetrinae of the family Antedonidae. The comatulids as a group are unknown before the Jurassic and are always rare as fossils. The specimen represents a type most abundant in recent seas and is much like a living Alaskan form. Knowledge of the fossil forms is so scant that an exact statement of age is impossible, though the close relation to a living crinoid suggests Cretaceous or later.

The age of this group of apparently conformable formations can not therefore be given more closely than post-Triassic, with the added suggestion that this group, the oldest of the region, may be Cretaceous or later.

GRAYWACKE OF WESTERN BAINBRIDGE ISLAND AND KENAI PENINSULA.

The bedrock of the western part of Bainbridge Island and the eastern shore of Kenai Peninsula is a group of sedimentary rocks, composed of interbedded graywacke, argillite, slate, and conglomerate. The eastern limit of this group extends from the bay in the north end of Bainbridge Island southwestward to Hogg Bay. The western limit is unknown. This group is made up largely of gray-

wacke, but the proportion of other types of sedimentary rocks varies widely. At the north end of Bainbridge Island there is a broad belt of slate and graywacke, to the west of which lies a high ridge of massive graywacke. The west shore of Bainbridge Island and the west side of Bainbridge Passage consist of very massive graywacke with very little slate. This group must comprise several thousand feet of strata. The formations as a whole are of a dark-gray color; the slate is bluish black, and the graywacke dark gray. The graywacke of Bainbridge Passage differs from the bedded graywacke of Latouche Island in the absence of definite, straight, and abundant bedding planes. Here and there narrow belts of thin-bedded graywacke and argillite show in the more massive graywacke. On Hogg Bay, on Bainbridge Island, some conglomerate occurs interbedded with slate, argillite, and graywacke. The matrix of the conglomerate ranges from siliceous to argillaceous. The pebbles are small and well rounded. A noteworthy feature of this conglomerate is the presence in it of greenstone pebbles. The conglomerates of Latouche, Hoodoo, and Knight Islands are not known to contain pebbles of similar lithologic character.

So far as is known at present this is the youngest rock group in the Latouche and Knight Island districts. No fossils have yet been found in any part of the group, and therefore exact evidence as to its age is not available. Nor are its contacts with the other rock groups of these two districts sufficiently distinct to permit definite statements as to its age relations. The situation of this group to the west of and apparently overlying the other groups; the absence of basic intrusions in it; the more massive character of the graywacke of this group as opposed to the bedded nature of the graywacke of Latouche and Knight islands; and the presence of greenstone pebbles in the conglomerate on Hogg Bay, all appear to indicate a later age for this group of rocks, with a probable marked erosional unconformity between it and the next older greenstone group. The evidence on this point, however, is not conclusive, and it is possible that this group is to be correlated with the bedded graywacke of Latouche and Knight islands.

GREENSTONES.

The rocks locally called greenstones are greenish altered igneous rocks, comprising a thick series of lava flows, volcanic tuff, and agglomerate, with associated dikes and larger intrusive igneous masses. All these rocks are basic. They intruded or flowed out over the surface of the graywacke, slate, and conglomerate which form the sedimentary portion of the eastern islands of this group, and they appear to be overlain by the massive graywacke of western Bainbridge Island and Kenai Peninsula. The different types are inti-

mately associated, are probably genetically related, and are of about the same age. No very definite evidence is available regarding the age of these igneous rocks, and at present it can only be said that the volcanic activity took place either in the Jurassic or in some later period.

The greenstones are the most widespread group of rocks in these districts. They cover all of Knight Island except the peninsula between Snug Harbor and Mummy Bay, which is composed of sedimentary rocks that are older than the greenstone but are intruded by many sills, dikes, and masses of it. Elrington Island, except for a small central portion, is almost wholly greenstone. Hoodoo and Flemming islands are largely greenstone, and intercalated in the slates of the eastern and southern parts of Bainbridge Island are many basic sills. A few small sills also intrude the rocks of Latouche and Danger islands. The largest single area of igneous rock is that of Knight Island. This area extends from Point Eleanor south to the entrance of Mummy Bay, a distance of a little over 25 miles, and its maximum width is about 9 miles.

The greenstones vary widely in texture, ranging from aphanitic to coarse-grained rocks. Both porphyritic and nonporphyritic types occur. Diabasic and amygdaloidal textures are also seen. The color of the rocks varies considerably, ranging from light greenish gray to dark greenish black. Some of the rocks have slight reddish tints, and fragments of reddish lava occur in some of the agglomerate. Ellipsoidal flow structure is visible in many places along the shores of Knight Island, but the rock in the central part of the island is more massive, shows little evidence of ellipsoidal structure, and presents wide color and textural ranges. Gneissic texture is shown in places. Ellipsoidal structure is also found on Flemming, Elrington, Hoodoo, and some of the smaller islands. Tuffaceous and agglomeratic beds occur on Elrington and Knight islands. Dark-colored fine-grained basic dikes cut both the ellipsoidal greenstones and the central massive core of Knight Island in several places. In some parts of the districts chloritic schist has been developed by the shearing of the greenstones by later movements.

MINERAL RESOURCES.

GENERAL FEATURES.

The mineral resources of the Latouche and Knight Island districts consist of lode deposits containing as valuable metals copper, silver, and gold. Copper is the predominant valuable metal in the lodes of both districts, but silver or gold or both are obtained from the copper-bearing deposits.

The first mineral locations on both Latouche and Knight Islands appear to have been made in 1897. The Beatson-Bonanza mine was the first property staked. Other locations on both islands followed, but little work was done on most of the property. Development work was started on the Beatson property, and a small trial shipment of ore was made in 1889. Other shipments followed, and in 1903 over 100 tons was shipped. Regular shipments from this mine began in 1904 and have continued ever since.

Prospecting was especially active in these districts from 1903 to 1907, and culminated in the latter year in a decided copper boom. Practically all of Latouche and Knight islands was staked at that time, and many of the locations were made on showings of little worth under any conditions. Extensive developments were started on several properties. The boom did not last long, however, and its natural collapse was assisted by a sharp drop in the price of copper and the period of financial stringency of 1907 and 1908. In but few places has the development work in progress at that time been continued or renewed. No new regular producers have appeared. Test shipments, some of which amounted to several hundred tons, have been made from a number of properties on Latouche and Knight islands, and small trial shipments have been made from some of the other properties.

The world-wide demand for copper that began in 1914 caused renewed activity in this portion of Prince William Sound, and, although there has been no increase in the number of producers, the Kennecott Copper Corporation has markedly increased the productive ability of the Beatson-Bonanza mine. In 1916 development work was in progress at this mine and on the properties of the Reynolds Alaska Development Co., on Horseshoe Bay, and the Seattle Alaska Copper Co., on Montgomery Bay, on Latouche Island; and the annual assessment work was done on numerous other claims.

The area considered in this report lies entirely within the Valdez recording district, the recording office of which is at Valdez.

GEOGRAPHIC DISTRIBUTION OF THE COPPER DEPOSITS.

The Latouche and Knight Island copper districts are the southwesternmost two of several more or less isolated copper-bearing districts that lie scattered along the shores of Prince William Sound from Cape Whitshed to Cape Puget.

The copper mineralization in the southwestern part of Prince William Sound is, so far as known, restricted to the islands of the Latouche and Knight Island districts. These two districts are more or less mineralized throughout their entire length and breadth, and consequently the mineral belt trends northeastward with the general

geographic trend of the islands included in the districts. Copper deposits have been found on Knight, Latouche, Elrington, and Bainbridge islands. They are especially abundant in the greenstones on Knight Island, although it is in the sedimentary rocks of Latouche Island that ore bodies of proved commercial value have thus far been found. The known deposits on Elrington and Bainbridge Islands are few, small, and economically unimportant, but they serve to show the widespread extent of the mineralization.

The mineralization has a known vertical range of at least 1,550 feet. It is found below sea level in the Beatson Bonanza mine, on Latouche Island, and extends to an altitude of 1,500 feet at prospects on both Latouche and Knight islands. Copper deposits have been found distributed throughout this vertical range.

The only regularly producing property within these two copper districts is the Beatson-Bonanza mine of the Kennecott Copper Corporation, at Latouche. Small shipments of copper ore have been made to smelters from prospects on both Latouche and Knight islands.

GEOLOGIC RELATIONS OF THE ORE DEPOSITS.

Certain definite geologic conditions, partly structural and partly chemical, have caused the present geographic distribution of the ore deposits. The mineralizing solutions appear to have been genetically related to the basic intrusive rocks. The ore deposits occupy brecciated or sheared zones in both the sedimentary rocks and the greenstones of these districts. The steeply dipping sediments of Latouche and Knight islands are crosscut and intruded by the greenstones, and the bedding planes of these sedimentary rocks, together with the many dip and strike faults, offered favorable channels for the ore solutions. Shear zones were also developed in the greenstones of Knight Island by diastrophic movements during the succession of intrusions and extrusions which built up that island. Many of these shear zones are more or less mineralized.

Within the greenstone area of Knight Island evidences of sulphide mineralization are so abundant as to indicate a source near by for the mineralizing solutions. The presence of chalmersite within this area is perhaps significant of the same thing. The mineralization of the other greenstone areas of the Latouche and Knight Island districts is slight, and prospects are known only on Elrington and Bainbridge islands.

Many copper-bearing prospects have been found within the older sedimentary rocks both on Knight and Latouche islands. It is within these rocks that the ore bodies of the Beatson mine at Latouche, the Reynolds Alaska Development Co.'s prospect at Horseshoe Bay, and the other Latouche Island properties lie. Sporadically distributed through certain portions of these rocks are limestone

and other calcareous sediments. At Horseshoe Bay undigested fragments of limestone are found in the solid sulphides, and beds of siliceous limestone were cut in some of the workings. The upper argillaceous part of this group of the older sedimentary rocks, as exposed on Elrington, Hoodoo, and Bainbridge islands, appears to have presented unfavorable conditions to the formation of sulphide ore deposits.

No copper deposits are known to have been found within the areas underlain by the massive graywacke series of western Bainbridge Island and the adjacent mainland of Kenai Peninsula, which apparently were laid down after the cessation of cupriferous mineralization.

The ore bodies are impregnation and replacement deposits of sulphide ores. Classified on the basis of the dominant valuable metal, the ores are copper ores. From a metallurgist's point of view they are base smelting sulphide ores with a high copper content.

The mineralogy of most of the ores is simple; the minerals are few and are common to most of the properties. Certain of the Knight Island prospects, however, contain chalmersite, a rare copper-iron sulphide not observed in most of the copper-bearing ores of the two districts.

The economically important copper-bearing minerals are chalcopyrite and chalmersite, which occur intimately associated at some of the Knight Island prospects. Gold or silver, or both, occur in some of the ores. The gold is probably native. The combination in which the silver occurs is not known.

The original metallic minerals of these ores are chalcopyrite, chalmersite, pyrrhotite, pyrite, sphalerite, galena, gold, and silver. Traces of arsenic and nickel are reported in some of the ores. The nonmetallic minerals include quartz, feldspar (?), chlorite, a brown-weathering cream-colored carbonate, calcite, and epidote.

Minerals resulting from the weathering of the original ore minerals are native copper, chalcocite, covellite,[1] melaconite,[2] malachite, azurite, and the yellow and red oxides of iron. These secondary minerals are of no economic importance because of their scarcity, the ore bodies having been but slightly oxidized since the comparatively recent glaciation of these districts.

MINES AND PROSPECTS.

The descriptions of the mine and prospect workings as here given must be regarded in the main as representing the conditions in the

[1] Grant, U. S., and Higgins, D. F., Reconnaissance of the geology and mineral resources of Prince William Sound, Alaska: U. S. Geol. Survey Bull. 443, p. 54, 1910.

Lincoln, F. C., The Big Bonanza copper mine, Latouche Island, Alaska: Econ. Geology, vol. 4, p. 212, 1909.

[2] Grant, U. S., and Higgins, D. F., op. cit., p. 54.

fall of 1916. All the prospects within these two districts were not visited in 1916, and consequently no description can be given here of the prospects not seen. The absence of people on many of the bays and the fact that only a few properties were under development during the summer prevented the visiting of many prospects and the obtaining of more detailed descriptions of many others. In the following descriptions the elevations have ordinarily been obtained by the use of aneroid barometers. The distances underground were measured by pacing. All bearings have been corrected for magnetic variation. The amount of space devoted to a prospect is no measure of its economic value.

LATOUCHE ISLAND.

KENNECOTT COPPER CORPORATION.[1]

The property of the Kennecott Copper Corporation is on the west side of Latouche Island, about 2½ miles from the north end of the island. (See Pl. XII.) The mill, power plant, and other camp buildings are on tidewater. The Beatson-Bonanza mine, on the Big Bonanza No. 1 claim, is in the precipitous western face of a low hill about half a mile southeast of the wharf. The Chinega workings are little over 1,000 feet north of the Beatson-Bonanza mine, on the Chinega claim.

The ore body now under development at this property is that of the Beatson-Bonanza mine. It was located in July, 1897. The first shipment of ore is said to have been made in November, 1899. In recent years shipments have been made regularly, and the mine has steadily increased its output. An oil flotation plant was put into operation in 1915, and both crude ore and flotation concentrates have since been shipped. In 1916 the capacity of the mill was being largely increased.

A large private wharf furnished landing facilities for ocean-going steamers. A tram line, covered with snowsheds, connects the wharf with ore bunkers, store, mill, and the Beatson-Bonanza workings. Large ore bunkers have been erected on the wharf and on the shore near by. Bunk houses, mess house, staff house, office, store, cabins, hospital, mill, wireless plant, power house, and crude-oil storage tanks are situated along the shore of the bay. The power plant consists of boilers fired with crude oil, steam turbines, air

[1] Other descriptions of this corporation's property on Latouche Island are given in the following publications:

Grant, U. S., Copper and other mineral resources of Prince William Sound: U. S. Geol. Survey Bull. 284, p. 82, 1906.

Lincoln, F. C., The Big Bonanza copper mine, Latouche Island, Alaska: Econ. Geology, vol. 4, pp. 201–213, 1909.

Grant, U. S., and Higgins, D. F., Reconnaissance of the geology and mineral resources of Prince William Sound, Alaska: U. S. Geol. Survey Bull. 443, pp. 63–66, 1910.

compressors, and dynamos. The mill is electrically operated, and the entire property above ground and part of the mine are electrically lighted. Air drills are used in the mine.

The underground workings of the Beatson-Bonanza mine in October, 1916, comprised a large open cut (the Bluff pit), workings on the face of the bluff, several tunnels in the face of the bluff, several large open cuts on the top of the hill east of the bluff, the main level, with nearly 6,000 feet of drifts and crosscuts, several raises to the Bluff pit, a 100-foot winze from the main level to the 100-foot level, and about 1,750 feet of workings on the 100-foot level. A main working shaft has also been started near the mill and connected with the main level.

On the adjacent Chinega claim the underground developments are reported to consist of two tunnels, some drifts, and a raise, aggregating a few hundred feet.

The ore taken from the Beatson-Bonanza mine is of two grades—a shipping ore and a milling ore. The higher-grade ore is shipped direct to the Tacoma smelter. The lower-grade ore is crushed and classified, and the sulphides are recovered by an oil-flotation process. The concentrates, after drying, are shipped to the Tacoma smelter.

The country rock on this property consists of an interbedded series of sedimentary rocks disturbed by many small strike and dip faults, and minor drag folds. The rocks range from very fine-grained black slate and argillite and light-gray structureless chert to coarse-grained light-gray graywacke and conglomerate. At the Beatson-Bonanza mine graywacke, chert, slate, and argillite form the country rock of the ore body. Between the mine and the shore is a wide slate belt, and on Powder Point occur conglomerate and graywacke. The strike of the sedimentary rocks near the Bonanza ore body is about N. 20° E. and the prevailing dip is 65°–70° W. Steep easterly dips appear locally short distances west and north of the Beatson-Bonanza workings. No igneous rocks are known to occur in the vicinity of the ore bodies.

The Beatson-Bonanza ore body consists of a roughly lenticular mineralized mass of shattered and sheared sedimentary rocks. The steeply westward-dipping interbedded sediments of the ore zone are cut by a linked system of faults inclosing large horses of country rock surrounded by softer sheared material. On the lower level the ore body has a northeasterly strike and a steep westerly dip. On the main level the strike is slightly more northerly. The hanging wall of the ore zone is sharp and definite. On the footwall side the ore gradually fades out into the massive graywacke. The ore has been formed by replacement and impregnation of the country rock and filling of fractures. The soft sheared material surrounding the horses

of country rock is largely replaced by sulphides. Lenses of solid sulphides as much as 10 feet in thickness occur in places close to the hanging wall. Much of the graywacke within the ore body contains disseminated chalcopyrite.

The ore body on the Chinega claim is reported to be a shear zone containing chalcopyrite and other sulphides in streaks of solid sulphides as well as disseminated through the sheared material.

The primary metallic minerals in the Bonanza ore include chalcopyrite, pyrrhotite, pyrite, sphalerite, galena, silver, and gold. Traces of arsenic and nickel have been revealed by assays.[1] Chalcopyrite is the only copper-bearing mineral present in the primary ore. Chalcopyrite, pyrrhotite, and pyrite are the dominant sulphides; sphalerite occurs in much smaller amounts, and there is only a little galena. Only a trace of gold is shown by assays.

The primary nonmetallic minerals form but a small percentage of the ore. They include quartz, a brown-weathering cream-colored carbonate (probably the same mineral referred to by Lincoln[1] as ankerite), calcite, and chlorite. Secondary minerals, formed by the weathering of the outcrop of the ore body and by the weathering of ore pebbles in the overlying talus and glacial till, include native copper, covellite,[2] chalcocite, malachite, and limonite.

REYNOLDS ALASKA DEVELOPMENT CO.

The Reynolds Alaska Development Co. holds several claims on Horseshoe Bay, on the west coast of Latouche Island, about 2 miles southwest of the Beatson-Bonanza mine. The company has built a small town on the shore of Horseshoe Bay. A corduroy road leads from the shore camp to the mine workings on the Duke and Duchess claims, at elevations of approximately 150 and 400 feet, respectively, and distances of half and three-quarters of a mile from the shore of Horseshoe Bay.

The ore bodies on this property are said to have been located about 1898. Grant[3] states that in 1905 a 50-foot tunnel had been run on the southern ore body and a branching tunnel 300 feet in length driven on the Duchess claim. In 1907 a shaft was sunk on the Duke claim and a small amount of ore was shipped. The wharf, electric-light plant, trading store, and a number of houses were also erected during that year.[4] in 1908[5] the shaft, reported to be 100 feet deep,

[1] Lincoln, F. C., The Big Bonanza copper mine, Latouche Island, Alaska: Econ. Geology, vol. 4, p. 209, 1909.

[2] Idem., p. 212.

[3] Grant, U. S., Copper and other mineral resources of Prince William Sound: U. S., Geol. Survey Bull. 284, p. 85, 1906.

[4] Moffit, F. H., Notes on copper prospects of Prince William Sound: U. S. Geol. Survey Bull. 345, p. 178, 1908.

[5] Grant, U. S., and Higgins, D. F., Copper mining and prospecting on Prince William Sound: U. S. Geol. Survey Bull. 379, pp. 88–89, 1909.

with a crosscut at its bottom to an ore body, was full of water. At that time the development work on the Duchess claim consisted of about 2,000 feet of tunneling. An average force of 10 men was employed in 1916. The shaft on the Duke claim was pumped out, and the drifts along the ore body were extended. On the Duchess claim development work was in progress on the lower level.

On the Duke claim, in 1916, there was a 110-foot two-compartment timbered shaft, with a 200-foot crosscut 100 feet below the collar of the shaft, cutting the ore body 100 feet from the shaft, and with drifts 44 and 67 feet in length along the footwall of the ore body to the south and to the north, respectively. A crosscut was also being started west from the shaft at the 100-foot level. A short distance southeast of the shaft a 60-foot tunnel has been driven southward along a solid sulphide lens. On the north side of the creek, north of the shaft, a prospecting tunnel has been driven. Some stripping and open-cut work has also been done. The Duchess workings comprise two main tunnels at elevations of approximately 400 and 500 feet, with drifts and crosscuts aggregating 1,000 and 1,800 feet, respectively, a 10-foot tunnel at an elevation of about 630 feet, and some open cuts and strippings.

Surface improvements other than those previously mentioned include the power plant on the shore of the bay, consisting of flume and pipe line leading to a Pelton wheel belt-connected to one alternating-current generator and one direct-current generator; transmission lines to both the Duke and the Dutchess workings; a continuous-current electric motor gear-connected to hoist, a small motor-driven fan for ventilating, a motor, and an electric pump at the Duke shaft; a motor (belt-connected to air compressor), air line, and drills on the Duchess claim; and buildings near both workings. A stream running through the property furnishes water power.

The country rock in the vicinity of the ore bodies consists principally of interbedded graywackes and black slates. There is also some light-gray slate, a little chert, and a small amount of limestone. Beds of light-gray siliceous limestone are exposed in the Duke workings. The bedding of these sedimentary rocks strikes N. 16°–38° E., and the dip is mostly westward, ranging between 55° W. and 83° E. There is some faulting more or less parallel to the strike and dip of the bedding. One gouge-filled fault, cut in the lower workings on the Duke claim, strikes N. 30° E. and dips 50° W. The footwalls of both the Duke and the Duchess ore bodies consist of thick beds of black slate. Graywacke predominates in the hanging walls.

Two mineralized bodies of rock have been under development on this property. These lie along a northeastward trending line and are separated by a heavily covered unprospected area nearly 1,500 feet in length, in which a small exposure of ore is said to have been

observed in the bed of a stream. The northeasterly ore-bearing body, developed by the Duchess workings on two levels about 100 feet apart, consists of a solid sulphide lens with a developed length of about 500 feet. The thickness of this lens ranges from 6 inches to 122 feet, but the average is probably between 25 and 30 feet. Some beds of graywacke and black slate are interbedded with the sulphides in the thicker portion of the lens. The strike of this sulphide lens is a little east of north, and the dip is nearly vertical. A shear zone 1 inch to 8 feet thick follows the hanging wall of the lens, and a little ore in stringers and lenses occurs scattered through the sheared material. Chalcopyrite is reported to be more abundant in this shear zone than in the solid sulphide lens. The graywacke hanging wall is also slightly mineralized.

The sulphides in the ore are chiefly pyrite and pyrrhotite. Chalcopyrite is the copper-bearing mineral, and sphalerite and galena (?) are also present. There is a small gold and silver content. Small unreplaced remnants of limestone are visible in the heavy sulphide ore. Some quartz is present in the ore, and small sulphide-bearing quartz stringers occur in the country rock adjacent to the ore body.

On the Duke claim the width of the outcrop of the mineralized zone appears to be between 200 and 250 feet. The shaft developments show but a single ore body—a westward-dipping sulphide lens with a maximum thickness of 27 feet and a developed length of about 140 feet. Where this lens is crosscut the hanging wall dips 80° E. and the footwall 65° W.; the strike is about N. 35° E. Isolated mineralized croppings occur whose relations to one another and to the sulphide lens shown in the shaft workings are not known. A 60-foot tunnel has been driven southward along a 5-foot sulphide lens a short distance southeast of the shaft. This lens strikes N. 20°–45° E. and dips 60°–75° W. In the creek north of this tunnel 10 feet of solid sulphides is exposed, and another outcrop on the north side of the creek shows 6 feet of solid sulphides.

The sulphides in the Duke ore include chalcopyrite, pyrite, and pyrrhotite. Quartz is present in small amounts as a gangue mineral.

LATOUCHE COPPER MINING CO.

The ore body under development on the property of the Latouche Copper Mining Co. is on the Blackbird claim, about half a mile north of the Beatson-Bonanza mine of the Kennecott Copper Corporation and about 2,000 feet from the shore. The ore body crops out at an elevation of about 400 feet above sea level, and the mouth of the long crosscut tunnel giving entrance to the workings is about 200 feet above sea level and 1,500 feet southeast of the shore end of the tram.

The underground developments on the property consist of a crosscut tunnel, about 750 feet in length, commencing on the White Wing claim and driven in a direction a little south of east, cutting the formation nearly at right angles and crosscutting the ore-bearing ground on the Blackbird claim. There are also about 600 feet of drifts and crosscuts, some stopes, and raises, one of which reaches the surface. A 35-foot crosscut tunnel has been driven a few feet above sea level at the shore end of the tram.

The surface developments consist of numerous open cuts, some shallow shafts, trenches, and pits on and across the ore zone. A blacksmith's cabin has been erected at the mouth of the long crosscut tunnel, and two small sheds stand near by. A tram line connects this tunnel with ore bunkers on shore. Several hundred tons of copper ore is said to have been shipped from this property.

The country rock of the ore body includes fine-grained graywacke, black and gray slates, gray chert, silicified limestone, and a little calcareous schist.

The ore deposit consists of a mineralized brecciated zone of interbedded sedimentary rocks. The width of the mineralized zone at the outcrop is about 40 feet, and the length, as exposed, is about 325 feet. The general strike of the outcrop is N. 5° E. Underground the strikes of the shears within the ore zone range from N. 5° E. to N. 35° E. and the dip from 75° to 85° W.

Sulphide-bearing quartz stringers and lenses occur within the ore zone. The minerals observed in the ore are chalcopyrite, pyrite, pyrrhotite, sphalerite. limonite, quartz, and calcite.

SEATTLE-ALASKA COPPER CO.

The property of the Seattle-Alaska Copper Co. is on Montgomery Bay, on the west side of Latouche Island, about 2 miles from its south end and 6 miles southwest of Latouche. Part of the camp buildings, consisting of two houses and two sheds, are on the shore of the bay. A wet trail meanders upward through timber dotted with open spaces from the camp buildings to the mineral deposits under exploitation. At an elevation of 700 feet, near timber line, there is a frame house and a wooden mill building. The mill building houses a Pelton wheel driving an air compressor. The air is piped to the working face of the lower tunnel. Most of the milling machinery has been removed from the property, and only a crusher and a table remain. The mill is reported to have been erected about 1911 and to have run only a short time. A telephone line extends from the mill to the lower tunnel.

The mine workings are above timber line in the north wall of a westward-facing cirque at elevations of 1,150 to 1,450 feet. The lower

tunnel, at an elevation of 1,150 feet, is 400 feet in length. In August, 1916, three men were at work in this tunnel, and one air drill was being operated. The next higher tunnel, at an elevation of about 1,350 feet, has about 400 feet of workings. At an elevation of 1,450 feet is a 40-foot tunnel, just above which is an open cut on the outcrop of the ore body. A short tunnel is reported in the north side of the same ridge in which the above tunnels are driven. The company is also reported to own several claims on the south end of Latouche Island, but no development work has been done on these claims recently.

The country rock in the vicinity of the ore deposit is dominantly graywacke with a small amount of black argillite and slate. The strike of the bedding is northeast, and the dip is about 70° W., with some vertical and some steep easterly dips on the limbs of small drag folds.

The ore body is apparently a mineralized shear zone ranging in width from an inch or less to 5½ feet. The strike is N. 35°–50° E. and the dip 70°–80° W. An open cut on the outcrop of the ore body exposes a mineralized sheared slaty lens, with a maximum width of 3.3 feet, containing narrow stringers of sulphides parallel to the schistosity. In the upper tunnel the sheared zone is only slightly mineralized and has a maximum width of 3 feet. The middle tunnel contains two drifts 20 and 50 feet in length driven on mineralized shear zones ranging from 18 to 66 inches in thickness.

Chalcopyrite is the predominant sulphide in the ore, but some pyrrhotite and a little sphalerite were also observed. Gold is reported in assays. Quartz is present in small amounts as a gangue mineral.

LATOUCHE ISLAND COPPER MINING CO., LTD.

The claims of the Latouche Island Copper Mining Co. (Ltd.) are on the eastern timbered slope of Latouche Island. The first showings are said to have been discovered between 1897 and 1899. Several hundred feet of tunnels have since been driven on widely scattered showings at elevations ranging from sea level to 700 feet above sea level. A two-compartment shaft has been sunk to a depth of 67 feet on one of the claims, and two log cabins and a large frame bunk and mess house have been erected near by. Several small shipments of ore are said to have been made since 1905. Only assessment work is reported on this property in recent years.

The country rock on the east side of Latouche Island consists of graywacke in beds from a few inches to several feet thick interbedded with some black slate and argillite and a little chert. The bedding has a northeasterly strike and dips 40°–65° W. There are numerous

faults parallel or nearly parallel to the bedding in strike and dip. Overturned drag folds show in places along the shore.

Many mineralized showings are reported on the different claims. Several of these were visited in 1916, but only the more promising ones are referred to here. The southernmost ore body examined was a 10-foot mineralized shear zone carrying considerable chalcopyrite exposed in a creek bank at an elevation of about 600 feet above sea level and also crosscut by a tunnel about 50 feet lower. On account of the heavy timber cover no attempt has been made to determine the length of this deposit. On the Alameda claim the graywacke along shore is mineralized for widths ranging from 4 to 40 feet, and this mineralized zone is traceable for some distance. Chalcopyrite occurs in small bunches and stringers scattered through this zone but is said to be the most abundant in a belt 4 to 10 feet in width. On another claim to the north of this one a 4-foot mineralized shear zone is exposed for a short distance. All the ore bodies are parallel or nearly parallel to the strike and dip of the bedding of the country rock. Chalcopyrite, pyrrhotite, sphalerite, and quartz are the usual ore minerals.

PROSPECTS ON KNIGHT ISLAND.

LOUIS BAY.

A 10-foot adit has been driven at sea level on a poorly delimited shattered zone in the greenstone on the south side of Disk Island. This zone strikes N. 55° E., dips 75° E., and is traceable for about 50 feet to the point where it disappears under cover. It has a maximum width of 4½ feet. The country rock consists of fine-grained dark-green greenstones and coarser light-colored greenstones. The shattered greenstone is both silicified and epidotized, and the ore contains, besides quartz and epidote, the sulphides pyrite, pyrrhotite, and chalcopyrite. Malachite and azurite occur as surficial oxidation products. Pyrite also occurs in the joint cracks of the hanging-wall greenstone.

A little development work has been done on some slightly mineralized areas near the head of Louis Bay. Two tunnels, each about 10 feet in length, have been driven just above high-tide level on small mineralized shear zones in greenstone. These two shear zones are about 20 feet apart. The northern one has a maximum width of 2.2 feet, strikes N. 50° E., and dips 75° S. Quartz, epidote, chalcopyrite, and pyrite occur in the crushed and shattered greenstone. The southern shear zone strikes N. 65° E. and dips 60° S. A short distance north of these two tunnels and a little higher is an open cut on an indefinitely delimited area of shattered greenstone, cemented by

quartz, pyrite, and epidote. The greenstone is also slightly impregnated with pyrite. At the head of the bay a little open-cut work has been done on a narrow shear zone in greenstone. This zone strikes S. 75° E. and dips 85° N. Pyrite was the only sulphide observed in specimens from this locality.

About 1½ miles south of the head of the bay over a graded trail there are two short tunnels driven in the greenstone ridge at the head of the valley. The lower tunnel, at an elevation of 540 feet, is about 90 feet long, with a 15-foot crosscut. A narrow, poorly defined shear zone is visible in the bluff over the tunnel mouth, but no ore was seen. The other workings, at an elevation of 830 feet, consist of a tunnel about 75 feet in length with a short drift and a winze at the junction of the drift and main tunnel. Both the winze and the drift were full of water in October, 1916. The greenstone country rock is somewhat sheared, but the shear zones are narrow, short, and only slightly mineralized. Quartz, epidote, chlorite, chalcopyrite, pyrrhotite, sphalerite, and pyrite form the ore minerals.

HERRING BAY.

A little development work has been done on Herring Bay on prospects formerly belonging to the Crown Copper Co. The prospects examined are at slight elevations above sea level and only a short distance from the shore. A tunnel 30 feet in length, with a 10-foot drift to the north, has been driven at an elevation of 110 feet in slightly shattered massive greenstone. Epidote stringers occur in the greenstone country rock, but no well-defined vein or shear zone was observed. No ore was found in place in the tunnel, but the few specimens of ore seen on the dump at the mouth of the tunnel contained quartz, epidote, pyrite, pyrrhotite, and chalcopyrite. There are some strippings and open cuts across the south end of a low hill west of this tunnel. The country rock is a shattered greenstone which is slightly mineralized at the western open cut. What ore there was at this locality must have occurred in very small lenses and stringers in the greenstone. None is visible in place now. A few ore specimens found on adjacent dumps contained quartz, pyrite, pyrrhotite (?), sphalerite, and chalcopyrite.

A little farther north on this same ridge is an open cut on shattered and slightly sheared greenstone. The shearing strikes N. 15° W. and dips about 90°. A small amount of sulphides is distributed through a zone which is stripped for a width of about 15 feet and is traceable continuously for about the same distance. The largest sulphide stringer was about 2 inches thick and about 3 feet long. The mineralization is irregular and very slight. Sphalerite, chalcopyrite, and pyrite are the principal sulphides.

LOWER HERRING BAY.

On the east side of the northeast arm of Lower Herring Bay, about halfway to the head of the arm, a short tunnel has been driven on a nearly flat-lying stringer, 1 to 6 inches thick, which cuts the greenstone country rock. Epidote is the predominant gangue mineral, and pyrite is the most abundant sulphide. Only a very little chalcopyrite is present.

BAY OF ISLES.

The development work on the Pandora property, on the Bay of Isles, has been done at an elevation of 380 feet above sea level on the west bank of a small stream that flows into the long southern arm of the bay. On the shore of the bay two cabins have been erected, and a trail extends from that point to the workings, which are below timber line. The surface developments near the ore body include two small sheds and a head frame for a shaft. Some open cuts and strippings have been made on the ore body. The underground work consists of an 85-foot tunnel with two drifts 15 and 20 feet in length, a crosscut 35 feet long, and a shaft sunk to a reported depth of 95 feet. At 9 feet from the bottom of the shaft, it is reported, drifts were opened on the ore for 65 feet in one direction and 45 feet in the other. Crosscuts were also driven short distances into both hanging and foot walls at a depth of about 65 feet and into the hanging wall at the lower level. Twelve or thirteen men were at work on the property early in 1916, but work was discontinued about the middle of June, and the shaft was full of water in September.

The ore deposit consists of several nearly parallel slightly mineralized shear zones in greenstone that incloses large unsheared horses of greenstone, around which the shear zones wrap and meet in strike and dip. The width of the sheared belt is at least 100 feet. The width of the individual shears ranges from 2 to 20 feet. The general strike of the sheared zone is N. 10°–15° W., and the dips recorded on the separate shear zones are 65°–80° E. The ore was formed by replacement and impregnation of the sheared material and as a filling of fissures. Sulphide lenses as much as 15 inches thick were observed, and the shaft is said to have been sunk on 5 feet of good copper ore. The ore minerals are chalcopyrite, chalmersite, pyrrhotite, and quartz.

RUA COVE.

The Copper Bullion claims, forming the Rua property, as it is commonly called, are on the east side of Knight Island about half a mile northwest of Rua Cove, an exposed indentation about midway in the east coast of the island. The workings are below timber line, at elevations of 360 to 750 feet above sea level. A trail leads from the

northwest corner of Rua Cove, past a cabin at an elevation of 200 feet, to the entrance of the lower tunnel. Here there is a blacksmith shop. This tunnel, about 365 feet in length, with crosscuts 5, 35, 35, and 60 feet in length, was the only underground work seen on the property. The surface developments consist of numerous open cuts and strippings on the outcrop of the ore body.

The country rock is dominantly greenstone, some of which shows an ellipsoidal structure, but some cherty and quartzitic rocks, possibly of sedimentary origin, occur in the outcrop of the ore body at an elevation of about 700 feet.

The ore body on the Copper Bullion claims appears to be a linked system of mineralized shear zones inclosing large horses of unsheared, unmineralized country rock. The general strike of this system of shear zones is about N. 30° E., and the dip is 55°–75° W. The ore exposures are on a southward-facing mountain slope between elevations of 360 and 750 feet. Above this point beds of massive unmineralized greenstones overlie the ore body. Another ore-bearing outcrop is reported farther north, however, where a creek is said to have cut down through these overlying lavas and exposed a mineralized shear zone. The tunnel at 360 feet above sea level is started on a shattered, slightly iron-stained zone in the greenstone. The first 300 feet of the tunnel contained no ore. A crosscut driven to the east at this point is for its entire length in more or less mineralized greenstone. The 35-foot crosscut to the west at the face of the tunnel crosses a 27-foot ore-bearing shear zone, the western contact of which has a strike of N. 30° E. and a dip of 75° W. At an elevation of 500 feet above tidewater a mineralized shear zone 50 feet in width strikes N. 5°–20° E. and dips 65° E. At an elevation of 540 feet and a little west of this shear zone is another mineralized shear zone which forms a well-marked gulch in the hillside. This zone strikes N. 25° E., dips 60° W., and has a width of several feet. Its hanging wall is massive unmineralized ellipsoidal greenstone. At an elevation of 610 feet the two last-mentioned shear zones join, and the combined zones extend up to an elevation of about 750 feet, where the outcrop pinches out beneath overlying greenstone flows. A trench 90 feet in length has been cut across the outcrop of the ore body at an elevation of about 700 feet. Lenticular masses of country rock are included within this shear zone, but the western 45 feet is nearly solid sulphides, and much of the remaining width is mixed ore and country rock.

Pyrrhotite is the predominant sulphide of the ore body, although some chalcopyrite is always present. Quartz also occurs associated with the sulphides.

DRIER BAY.

JONESY GROUP.

The Jonesy group of claims, at the head of Drier Bay, includes the ore deposit formerly known as the Bald Eagle. Considerable development work, including the erection of wharf, offices, ore bunkers, steam power plant, and aerial tram, was done on this property about 1907.[1] Of these improvements but two log cabins remain. The ore body, on which about 350 feet of underground work has been done, is about half a mile east of the head of the bay, at an elevation of about 1,000 feet. The country rock is greenstone. In the vicinity of the ore deposit a linked system of shear zones has been developed, and narrow bands of green schist wrap around horses of the massive greenstone. A narrow dike of fine-grained dark-colored basic rock has been intruded along one of the larger shear zones. These shear zones are more or less mineralized. The tunnel is driven on a zone of schistose greenstone which strikes N. 15° W. and dips approximately vertically. About 75 feet east of the mouth of the tunnel another shear zone, darker colored and more mineralized, crops out. This zone, which forms the main ore deposit, has been crosscut in the tunnel and opened by drifts for about 100 feet. It strikes N. 15° E. and dips 65° E. The width varies from less than an inch to 8 feet. A winze reported about 20 feet deep has been sunk on this shear zone, and some of the ore in the north drift has been stoped out. Chalcopyrite and pyrrhotite are the ore minerals.

MONARCH CLAIM.

The Monarch claim is about 1½ miles northwest of the head of the northern arm of Drier Bay. A trail leads from the shore to the underground workings, at an elevation of about 700 feet. These workings aggregate about 320 feet in length. No definite ore body was seen underground. The rock on the dump shows a small amount of pyrite and chalcopyrite impregnating a somewhat sheared greenstone. Epidote and quartz were present as gangue minerals. An iron-stained outcrop is reported to occur in the hills above the tunnel, but could not be located.

KNIGHTS ISLAND ALASKA COPPER CO.

The property of the Knights Island Alaska Copper Co. is located on an eastern arm of Drier Bay, known as Northeast Cove and Kiacco Cove. A cabin stands on the northeast shore of the cove, and a trail leads from this point past another cabin in a low saddle 700 feet above sea level to the underground workings one-third mile (in an

[1] Grant, U. S., and Higgins, D. F., Reconnaissance of the geology and mineral resources of Prince William Sound, Alaska: U. S. Geol. Survey Bull. 443, pp. 67–68, 1910.

air line) northeast of the cove, at an elevation of 950 feet. The underground workings consist of a crosscut tunnel about 650 feet in length, three drifts 20, 40, and 60 feet in length, a winze, and a raise. The country rock is greenstone. A very slightly mineralized zone of sheared greenstone, about 55 feet in width, was cut near the inner end of the tunnel, and two drifts were run in it. The winze was sunk on a 5-foot portion, which was somewhat more mineralized than the rest of the zone, and a raise was started above the winze. The outcrop of the ore body lies at an elevation of about 1,200 feet. The sheared belt strikes about N. 15° E. and appears to be traceable for a few hundred feet. The width of the shear zone ranges from 20 to 50 feet, but the walls are very indefinite and the zone includes horses of unsheared greenstone. A fine network of quartz stringers shows in the outcrop of the shear zone. The zone is only slightly mineralized as a whole, but in some places short bunches or lenses of solid or nearly solid sulphides occur in the sheared greenstone. A shallow shaft has been sunk on one lens 7 feet wide composed mostly of sulphides. Another sulphide lens 2 feet thick was observed. The minerals in the ore consist of chalcopyrite, chalmersite, sphalerite, pyrrhotite, and quartz. Basic dikes 1 inch to 12 inches thick and irregular masses of basic igneous rocks cut and intrude the mineralized shear zone.

COPPER COIN GROUP.

The Copper Coin group is on the south side of Drier Bay, between Barnes Cove and Mallard Bay, on a prospect formerly the property of the Russell Ball Copper Co. But little development work has been done on the property since it was visited by Grant and Higgins[1] in 1908. A cabin stands near the shore and a trail leads from the cabin to the workings. A wire-rope aerial tram, in operation in 1908, is now out of commission. The underground developments consist of a 60-foot adit, some short crosscut tunnels, and some open cuts. The adit, at an elevation of about 550 feet above sea level, is driven on an iron-stained shear zone in greenstone. This shear zone strikes N. 10° W., dips 70° E., and ranges in width from 10 inches to 10 feet. The widest part of the zone is at the mouth of this tunnel, and here, in the shear, are several lenses of solid sulphides from mere seams to some 6 inches in thickness. A vein of solid sulphides 3 to 12 inches thick lies along the footwall of the shear zone. Considerable quartz is present in the shear zone in places. At 40 feet above the tunnel, in the outcrop of the shear zone, here 8 feet in width, is a quartz lens 32 inches thick. The shear zone extends a considerable distance both up and down hill from the adit tunnel. At its lower end the zone is wider, appears to be less well defined,

[1] Grant, U. S., and Higgins, D. F., Reconnaissance of the geology and mineral resources of Prince William Sound, Alaska: U. S. Geol. Survey Bull. 443, p. 68, 1910.

and contains horses of unsheared greenstone country rock around which the sheared material wraps. The mineralization here is also less concentrated than at the tunnel. The minerals recognized in the ore from this property are chalcopyrite, chalmersite, pyrrhotite, and quartz. Limonite as a surficial product of weathering is present in the outcrop of the ore body.

MALLARD GROUP.

The Mallard group of claims is at an elevation of 1,500 feet in a gap at the head of Mallard Bay. The only development work consists of a shallow shaft and some open cuts. The country rock is entirely greenstone. The ore body appears as a large curved shear zone in greenstone with smaller shears wrapping around lenticular horses of massive greenstone along the footwalls of the main zone. This zone makes a marked depression in the gap, and at the time of visit in September, 1916, this depression was filled with snow, so that the major portion of the ore body was not visible. The footwall of the main shear zone, a steep bluff, strikes N. 35° E. at its south end and curves gradually to N. 80° E. at the north end. The dip is 60°–75° W. The exact width of the main shear zone was indeterminate on account of the snow cover but probably does not exceed about 20 feet. The part visible in September, 1916, was along the footwall in the northeastern half of the ore body. The main part of the ore body is said not to have been exposed at the time of visit, but ore carrying 5 per cent of copper is reported in the shaft. The minor shears exposed along the footwall are small and slightly mineralized. The ore minerals seen in specimens collected from this property are epidote, pyrite, chalcopyrite, and quartz. Gold is also reported.

NELLIE GROUP.

The Nellie group of claims is located over a mineralized shear zone that crosses a deep gulch about one-third mile northeast of the head of Drier Bay, at an elevation of about 650 feet. The development work on the property consists of five open cuts, a 6-foot shaft, and a 36-foot adit tunnel. The tunnel is driven northward, on the north bank of a westward-flowing stream, in a mineralized shear zone, which strikes N. 25° E. and dips 75° E. The country rock is greenstone. At the face of the tunnel the shear zone is 9 feet in width. A 12-inch band of sheared greenstone containing a 2-inch lens of solid sulphides lies along the west wall of the shear at the face. The rest of the zone at this point is filled with large lenses of greenstone, around which narrow strips of sheared greenstone wrap. On the south side of the creek the shear zone is about 20 feet wide and consists mostly of solid greenstone, with several layers of chlorite schist

18 inches or less thick. At an elevation of 770 feet on the south side of the gulch the shear zone, here 9 feet in width, is made up largely of a dark schistose mineralized rock. The southernmost exposure of this shear zone is at an elevation of 900 feet, where there was a showing 15 inches wide. On the mountain north of the tunnel the shear zone is traced by scattered outcrops and a few open cuts along its general strike, though it can not be said definitely that these showings are all in the same shear zone. They are not continuous, and in places the shearing is diffuse and the zone contains much massive greenstone and little schistose material. The showings, however, lie in a comparatively narrow belt trending N. 7°–25° E. and traceable for at least three-fourths of a mile. At an elevation of 1,200 feet on the mountain north of the tunnel a 5-foot shaft has been sunk on a 10-foot shear zone in greenstone, the strike of which is N. 7° E. and the dip 70° E. On the crest of the ridge, at an elevation of nearly 1,400 feet above sea level, the shear zone strikes N. 25° E., has a steep easterly dip, and ranges from 4 to 12 feet in width. The mineralization is slight in much of the zone. The minerals present in the ore are chalcopyrite, chalmersite, pyrrhotite, and quartz. Chalmersite was observed only in the shallow shaft.

OTHER PROSPECTS.

Assessment work is reported in 1916 on the U and I group and on the Alhambra group. The total development work on the Alhambra group is reported to consist of two tunnels, 60 and 100 feet in length, and four open cuts.

COPPER BAY.

A tunnel has been driven just above high-tide line on the northeast shore of Copper Bay. Camp buildings have been erected on the shore east of the tunnel. The country rock is a fine-grained dark-green igneous rock. The tunnel is driven in a slightly shattered greenstone in which some of the fractures are healed by epidote stringers or by small quartz veins carrying epidote and sulphides associated with slight sulphidic impregnation of the adjacent country rock. No definite ore body was seen, and little ore could be found either in the tunnel or on the dump. The minerals present in the ore specimens collected include epidote, quartz, calcite, pyrite (?), pyrrhotite, chalcopyrite, and sphalerite.

SNUG HARBOR.

On the north side of the entrance to Snug Harbor a short tunnel crosscuts an ore body which appears to be interbedded with the slate and graywacke. The ore body crops out a short distance west of the

tunnel mouth, where it has a width of 2½ feet. The strike is N. 35° E. and the dip 73° W. In the tunnel a slightly more easterly strike and a nearly vertical dip were observed. The maximum width of mineralization is about 5½ feet. In places there are lenses of solid sulphides 12 inches thick. Quartz, sphalerite, chalcopyrite, and pyrrhotite are present in the ore.

MUMMY BAY.

MINNIE CLAIM.

The Minnie claim lies east of the head of the northeast arm of Mummy Bay, at an elevation of 700 feet. An adit 140 feet in length has been driven on a small, slightly mineralized shear zone in a series of slate, graywacke, and intrusive greenstone. Chalcopyrite, sphalerite, pyrrhotite, and quartz are the ore minerals. A little secondary native copper appears on the weathered outcrop of the ore body.

HOME CAMP LODE.

The Home Camp lode is at the head of Mummy Bay. Between the shore and an elevation of 75 feet a series of open cuts expose a belt of shearing striking N. 20°–30° E. A shaft about 7 feet deep has been sunk at one point. The maximum width of the mineralized shear zone as stripped is 10 feet, and the ore deposit has been uncovered for about 165 feet. Several small sulphide lenses are scattered through this mineralized zone. The largest lens is 10 feet in length and has a maximum width of 10 inches, pinching out at both ends. The mineralization appears to be confined to sedimentary beds (slate and quartzite?) included in the greenstone. A crosscut tunnel 15 feet in length has been started at a slightly lower elevation and is being driven in a westerly direction to cut this belt of sheared sediments. The face of this tunnel is in black slate, the cleavage of which dips 80° W. The dip of the mineralized shear zone is nearly vertical. Quartz, pyrrhotite, chalcopyrite, sphalerite, and chalmersite constitute the ore minerals.

HOGAN BAY.

The only ore deposit examined in 1916 on Hogan Bay is on the south side of the bay just inside the entrance. A mess house and a bunk house stand on the mountain side at an elevation of about 125 feet above sea level but bear no evidences of recent occupation. A crosscut tunnel between 1,100 and 1,200 feet in length has been driven 40 feet above high tide about 300 feet west of the camp buildings. The country rock is massive-bedded graywacke. This tunnel has apparently not reached the ore body for which it was started, a

vein that crops out farther up the mountain to the southeast. At an elevation of 240 feet another tunnel, 260 feet in length, has been driven in a graywacke series into which a little greenstone has been intruded. The bedding near the mouth of the tunnel strikes N. 25° E. and dips 70° W. At 190 feet from the mouth of the tunnel drifts aggregating 105 feet have been driven in both directions on a shattered zone 1 to 4½ feet in width, which strikes N. 30 W. and dips 45° W. A short raise has been carried up on this zone in each drift. The mineralization is confined chiefly to a narrow belt 2 to 8½ inches thick along the footwall of the shattered zone. A short upper tunnel is reported to have been driven at an elevation of 450 feet. About 2 feet of ore is reported in places in the outcrop of the vein. Quartz, chalcopyrite, sphalerite, and pyrrhotite were observed in the ore.