GEOLOGIC FEATURES OF ALASKAN METALLIFEROUS LODES.

By Alfred H. Brooks.

INTRODUCTION.

Thirteen years of systematic investigation of the mineral resources of Alaska by the Geological Survey has yielded a large amount of information relating to the geology of the mineral deposits. This has been used for the most part only in the descriptions and discussions of the economic geology of the individual districts about which reports have been published. Heretofore relatively little attention has been paid to the relation of the mineral deposits of different parts of the Territory to one another or to other broader problems of economic geology. Practically the only exception is the geology of the coal fields, which has been briefly summarized.[1] Therefore anyone desiring information about the areal distribution and geologic occurrence of the metalliferous deposits must seek it in nearly two score publications.[2]

It is proposed to summarize briefly in this paper the salient geologic features of the metalliferous deposits of Alaska, using the results obtained by the many geologists who have worked in this field. As the facts and their interpretation are taken largely from published reports, it will be evident that this article can lay no claim to being an original contribution to the geology of the ore deposits. It is hoped that the matter presented will be useful, not only to those who are developing the metallic wealth of the Territory, but also to those who may desire a convenient outline of the more purely scientific results which have been achieved.

Alaska is rich in metallic wealth. Its lode and placer mines up to the close of 1910 have produced[3] about 8,411,467 fine ounces of gold, valued at $178,789,171; 2,130,199 fine ounces of silver, valued at $1,286,678; 33,795,108 pounds of copper, valued at $5,338,709; and about $100,000 worth of tin. The rapid advance of the mining

[1] Brooks, A. H., The coal resources of Alaska: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, pp. 515–571. Martin, G. C., The Alaska coal fields: Bull. U. S. Geol. Survey No. 314, 1907, pp. 40–46 Brooks, A. H., Alaska coal and its utilization: Bull. U. S. Geol. Survey No. 442, 1910, pp. 47–100.

[2] See list of publications at end of this volume.

[3] Statistics of mineral production are presented in detail on pp. 24–28.

industry, which had its beginning in 1880, is indicated by the fact that over 80 per cent of the gold, almost 75 per cent of the silver, and all of the copper and tin have been produced during the last decade.

The lode production, which is the more important to the subject of this paper, includes all the copper, 2,346,635 fine ounces of gold, valued at $48,662,775, and 1,001,241 fine ounces of silver, valued at $611,608. Of this amount, the copper, 1,544,916 fine ounces of gold (value $31,845,549), and 452,190 fine ounces of silver (value $262,630) have been produced in the last 10 years. Most of the tin is from placers, but there has been a small output from lodes.

The above statistics of the output of precious metals serve only to indicate the advancement in productive mining. Of more importance to the future of the industry is the large amount of work accomplished during the last few years in prospecting and developing lode deposits. This is true not only of long-established lode-mining camps on the Pacific seaboard but also of many inland districts. These developments are constantly adding new facts bearing on the occurrence of metalliferous lodes, and hence a paper like the present one can be regarded only in the nature of a progress report, which should be succeeded by others after more exhaustive studies of the several districts have been made.

GEOGRAPHIC AND GEOLOGIC DISTRIBUTION OF METALLIFEROUS LODES.

INTRODUCTION.

The distribution of the metalliferous lodes in Alaska is indicated on the accompanying map (Pl. I, in pocket), on which the localities of metal deposits are indicated by symbols. It would undoubtedly add much value to this paper if the distribution of the metals could have been shown on a geologic map, but such a map was not practical in this report, intended for early publication, because of the time needed both to compile the geologic data and to publish a map in colors. The larger features of the areal geology of some of the more important parts of the Territory are represented on Plates II, III, and IV, which will be supplemented by brief verbal descriptions of the geology of the entire province.

The general map (Pl. I) strikingly illustrates the very wide distribution of gold in the Territory. It will be shown that the gold is so widespread because the conditions for its deposition in the bedrock existed over large areas during Mesozoic time, rather than because there are many types of auriferous deposits or because they were formed during many epochs of geologic history. Copper, too, occurs in several widely separated districts, but there is less uniformity in the form of its occurrence than in that of the gold deposits.

The copper deposits are probably also chiefly of Mesozoic age. The tin deposits are practically all limited to one district and to one general epoch of formation.

The marked parallelism of the larger bedrock structures which prevails throughout much of Alaska has had a wide influence on the areal distribution of many of the stratigraphic subdivisions, and hence on the mineral deposits associated with them. These structures parallel the Pacific seaboard of Alaska, trending northwestward to about the one hundred and forty-ninth meridian, thence swinging to the west and southwest. As the position of the dominant mountain ranges and systems has been determined by these structures, their axes have the same trends.

The structures above noted have determined to a large extent the areal distribution of the bedrock formations, especially of those older than Upper Cretaceous. As a result of these tectonic lines, many of the geologic subdivisions occur in belts which parallel the Pacific seaboard. As it is impossible to present here a complete summary of the geology of Alaska, its larger features can probably best be elucidated by describing briefly the successive zones of rocks, similar in general lithology or age, which form the larger stratigraphic units, together with the metal deposits associated with them. These formations or zones will be described, so far as possible, in their geographic sequence from south to north. The order of treatment will have to be modified to a certain extent and some of the local geology will be presented by provinces, defined by drainage basins.

PACIFIC COAST REGION.

Four large stratigraphic units have been recognized in southeastern Alaska (see Pl. II). (1) A series of Paleozoic sediments locally interbedded with greenstones, including terranes varying in age from Silurian to Carboniferous and in places highly metamorphosed. The recent investigations of Knopf in the Juneau district show that locally, at least, Mesozoic sediments are closely infolded with some of these Paleozoic rocks and that some of these are highly metamorphosed. (2) A series of Mesozoic sediments (Lower Cretaceous or Jurassic) made up largely of clastic material. (3) The great batholiths of the Coast Range, comprising intrusive rocks varying in composition from granite to diorite and later than Middle Jurassic in age. Intrusive rocks of this age and composition are also widely distributed in isolated stocks or dikes. (4) Some small areas of Tertiary (Eocene) sediments and lavas.[1] In general, all these rock groups can be said to occur in a series of belts which are parallel to the northwest-southeast trend of the coast line. On the east the province is bounded by a broad belt of granitic intrusive rocks,

[1] There are also some recent lavas, which will not here be considered.

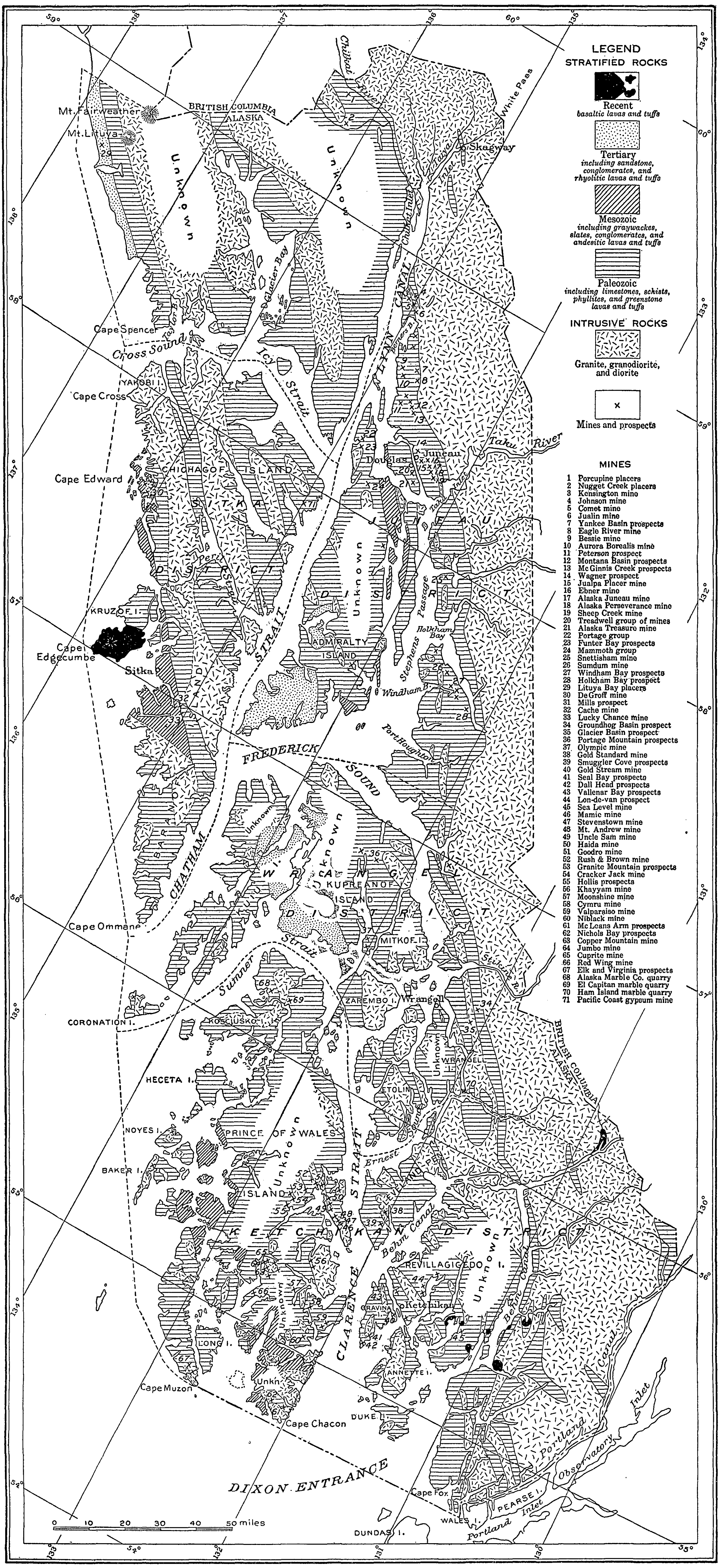
forming the Coast Range. Adjacent to these intrusive rocks on the west is a series of deformed Paleozoic and Mesozoic sediments. In most places a belt of metamorphosed sediments lies immediately adjacent to the granites of the Coast Range. A less altered series of Mesozoic or Paleozoic rocks lies next to the west. These have been locally metamorphosed by intrusive rocks lithologically similar to those of the Coast Range. The Mesozoic rocks occur in several broken belts within the areas of Paleozoic formations. One of the largest known of these belts skirts the westernmost islands of the Alexander Archipelago in the vicinity of Sitka.

The best-developed and largest known auriferous ore bodies of the Territory occur in a belt of Mesozoic and Paleozoic sediments (see Pl. II) skirting the mainland of southeastern Alaska and usually separated from the granitic batholiths of the Coast Range by a zone of crystalline schists a mile or more in width. Within this general zone of mineralization is included the Juneau gold belt, from which most of the lode gold of Alaska has been produced. This is a well-defined belt of mineralization from Snettisham on the south to Berners Bay on the north; but some gold has been found in both the northern and southern extensions of this belt.

In addition to the deposits occurring in this zone, auriferous quartz veins have also been found in or near the marginal zones of some of the outlying intrusive masses occurring in different parts of the Alexander Archipelago. Noteworthy examples of these auriferous lodes are those found in the slates and graywackes, probably of Mesozoic age, of the Sitka region. These rocks do not seem to have been metamorphosed by granitic intrusions, which are, however, not far distant. In southeastern Alaska auriferous deposits are also found within the intrusive masses themselves.

The Ketchikan district contains some important copper deposits. Of these, the best-known type is that which occurs in the contact zones of Paleozoic limestones and intrusive rocks, but there are also other types.

An extension of the strike lines of the formations of southeastern Alaska will carry them into the unexplored heart of the St. Elias Range. At Yakutat Bay two groups of rocks have been recognized. The eastern group, which probably forms the bedrock of the high ranges, is made up of crystalline and semicrystalline altered sediments, probably chiefly Paleozoic, with many intrusive rocks. The western, called the Yakutat group, consists of very highly contorted sediments, with some greenstones and other rocks, which have been provisionally referred to the Mesozoic. Little is known of the metalliferous resources of this district; but the fact that the glacial gravels derived from the St. Elias Range are locally more or less auriferous makes it probable that some gold-bearing quartz veins occur in the mountains.



GEOLOGIC RECONNAISSANCE MAP OF SOUTHEASTERN ALASKA.

Showing relation of ore deposits to intrusive rocks. By F. E. and C. W. Wright, 1907.

On tracing the coast line westward, metamorphic rocks of unknown age are found at Controller Bay, but are not known to carry any metalliferous deposits. These rocks are unconformably overlain by a closely folded sequence of Tertiary age bearing bituminous and anthracite coal.

Still farther west, on Prince William Sound, there is an older (probably Paleozoic) series of more or less altered sediments (Valdez group) overlain by a series of sediments and ancient lavas (Orca group), which are probably of Mesozoic age. Both series are closely folded and are locally cut by granitic intrusive rocks. The Chugach Mountains, which form the coastal barrier north of Controller Bay and Prince William Sound, so far as known, are made up of closely folded sediments, probably belonging to the same two groups of formations, and these are locally auriferous. In the western part of Prince William Sound the bedrock formations swing to the southwest, and the same groups of metamorphic sediments occur in the eastern part of Kenai Peninsula. These are succeeded near Kachemak Bay, on the southwestern part of the peninsula, by Mesozoic beds. Most of the western half of Kenai Peninsula is covered by little-disturbed Tertiary lignitic coal-bearing rocks and by Quaternary gravels. The geology of Kodiak Island is little known, but it is probable that metamorphic sediments of the same age as those of Kenai Peninsula form the dominating country rock, with small scattered areas of Tertiary lignite-bearing sediments.

On Prince William Sound cupriferous deposits have been found in association with the greenstones and sediments of the Orca group. Deposits of similar types occur near Resurrection Bay, an indentation of the northeastern part of Kenai Peninsula, and are reported from Kodiak Island. Auriferous quartz veins have been found at a number of places on Prince William Sound, occurring in slates and graywackes of both the Orca and Valdez groups. Similar types of occurrence are found in Kenai Peninsula in what is probably the extension of the same groups of sediments. Some gold deposits have also been found on Kodiak Island. None of these deposits are known to have such marked association with intrusive rocks as has been noted in the metalliferous veins of southeastern Alaska.

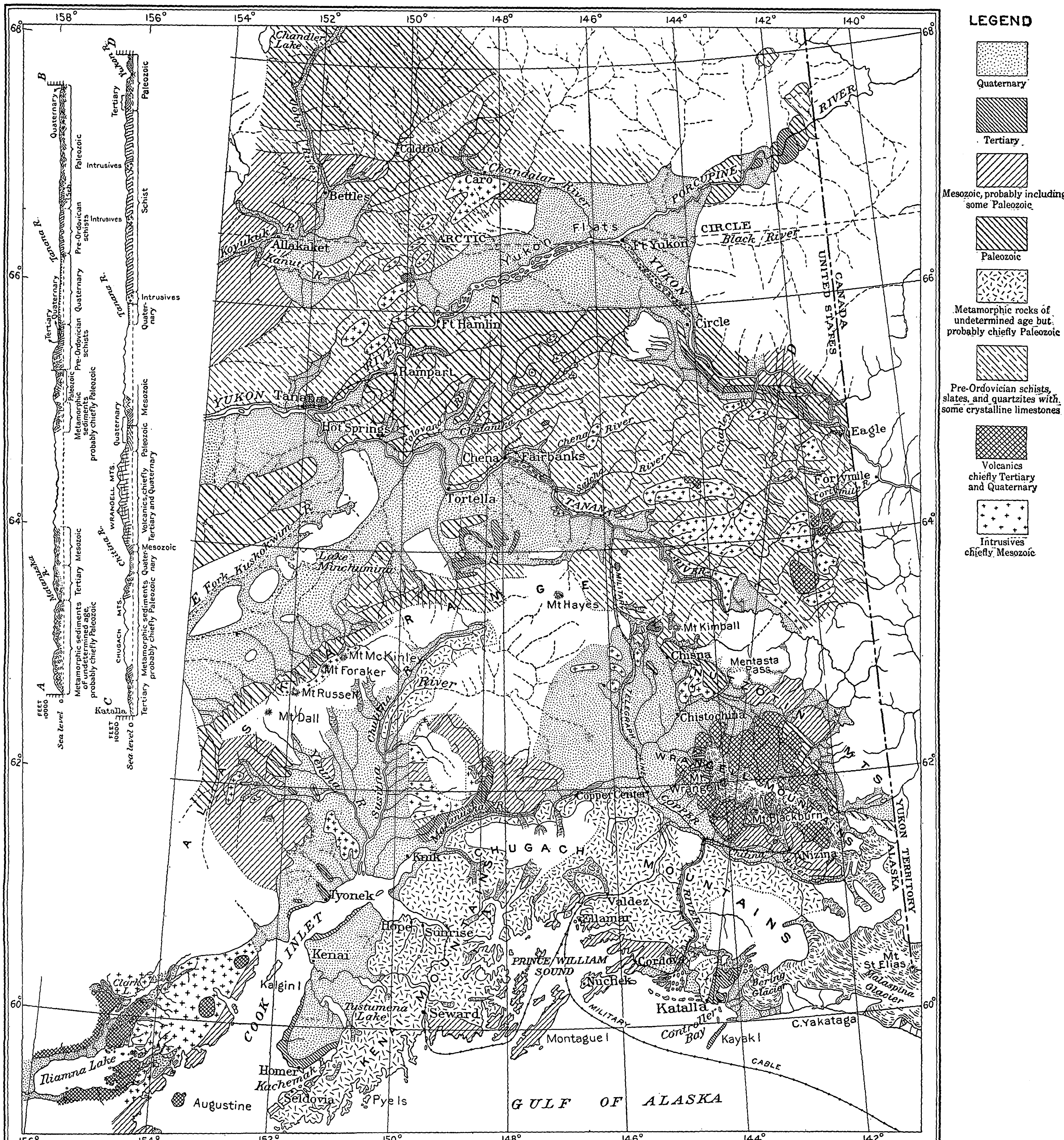
That part of the Iliamna region which lies adjacent to Cook Inlet is occupied chiefly by sediments and volcanic rocks of Mesozoic age, which are thrown into broad open folds. On the west the Mesozoic is bounded by a broad belt of granitic rocks locally altered to gneisses and probably intruded chiefly in Jurassic time. Within the granite area are some small belts of metamorphic greenstones, limestones, slates, and cherts, which may be Paleozoic but whose age is undetermined. Volcanic rocks and sediments, chiefly of Mesozoic age, lie adjacent to the granite on the west. These form the country rock of much of the shores of Iliamna and Clark lakes. In this field there are also some very extensive Tertiary and recent volcanic rocks. In the Iliamna region there are some auriferous and cupriferous ore bodies which occur chiefly in the altered sediments of Paleozoic or younger age at and near the contact of intrusive rocks. Some placer gold has been found in the Mulchatna basin, lying west of Lake Clark, but its geologic association is not known.

Mezozoic and Tertiary sediments and volcanic rocks, so far as known, form the country rock of much the larger part of the Alaska Peninsula and adjacent islands. The typical structures seem to be open folds with considerable faulting. Granitic intrusive rocks have not been found in that part of the Alaska Peninsula which has been examined, and there is but little evidence of metallization. The Aleutian Islands are unsurveyed and geologically almost unknown. It seems probable, however, that they are largely built up of volcanic rocks, of which a part are certainly recent, some may be of Tertiary age, and some are as old as the Mesozoic. Some intrusive granite stocks occur in this province.

The developed metalliferous deposits of southwestern Alaska are confined to Unga and Popof islands, where auriferous veins occur in lavas, probably of Mesozoic age. Some auriferous mineralization is, however, known at other localities, notably on Unalaska Island, where it is found in volcanic rocks (probably Mesozoic) near the contact with an intrusive stock of granite.

COPPER RIVER REGION.

The Chugach Mountains, which bound the Copper River basin on the south, are made up of closely folded sediments, more or less altered and intruded by igneous rocks, and carry some auriferous deposits. The broad alluvium-filled Chitina Valley, between the Chugach Mountains on the south and the Wrangell Mountains on the north, separates two provinces whose geology is quite different. (See Pl. III.) The Wrangell Mountains are probably formed by a broad syncline or synclinorium. Along the south arm of this syncline the sequence consists of a series of ancient volcanic rocks (Carboniferous or Triassic), called the Nikolai greenstone, succeeded conformably by the Chitistone limestone (Triassic), and this in turn by several formations of Mesozoic sediments capped by a great complex of volcanic rocks, which are in part recent and in part may be Tertiary. The north arm of the syncline, as exposed in the upper basins of White, Chitina, and Nabesna rivers, shows Carboniferous limestones and greenstones, succeeded by Mesozoic beds, and these in turn by the recent volcanic rocks. Mesozoic intrusive rocks are fairly abundant in these formations. The direct correlation of the older beds on the two arms of the syncline has not been possible with the



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1911

GEOLOGIC SKETCH MAP OF CENTRAL ALASKA.

By Alfred H. Brooks, 1909.

information at hand. On the west the Wrangell Mountains fall off to the broad gravel-filled basin which stretches from the Copper to the Susitna basin.

The best-developed ore deposits of this region are the copper-bearing lodes occurring along the southern flank of the Wrangell Mountains and chiefly in the basins of Kotsina and Chitina rivers, which are tributary to the lower Copper. These deposits occur in the Nikolai greenstone and Chitistone limestone, principally near the contact of the two formations. (See Pl. VI.) Copper occurs also on the northern flank of the Wrangell Mountains, in the basins of White River and of tributaries of the Tanana, where the associated sediments are, however, probably chiefly Paleozoic, and some of these deposits are along contact zones of intrusive diorite. The gold of the Nizina placers, in the upper Chitina basin, has been derived from quartz veins occurring in Upper Jurassic sediments near contacts with quartz diorite intrusive rocks.

North of the Wrangell Mountains lies a belt of closely folded Mesozoic sediments which constitute the Nutzotin Mountains. To the west these mountains merge with the Alaska Range, but there appears to be a marked change in their component strata. In the basin of the Chistochina the foothills of the Alaska Range are made up of upper Paleozoic sediments and volcanic rocks, with later intrusives. This series is separated by a great fault from a belt of metamorphic schists which constitute the greater part of the mountains to the north. On tracing these mountains westward, the geology is again found to change. In the upper Susitna basin the southern mountain front is made up of Mesozoic slates and greenstones of undetermined age which have been invaded by large masses of granitic rocks. In the heart of the range, however, the metamorphic schists are believed to dominate.

The gold of the Chistochina placers, in the northern part of the Copper River basin, appears to have been derived from quartz veins in Carboniferous sediments in a contact zone of intrusive granodiorites. No lode deposits have been developed in this field, but in the Nabesna basin, 60 miles to the east, some work has been done on a lode which appears to be a mineralized zone between a granodiorite and contact-metamorphosed limestone. The Valdez Creek placers have derived their gold from slates which are probably of Mesozoic age. These slates, like those of the Juneau gold belt, are separated from the granitic intrusive rocks by a zone of highly metamorphosed sediments.

SUSITNA AND MATANUSKA BASINS.

The region lying north of Cook Inlet falls into two general geologic provinces, separated by the Susitna Valley. (See Pl. III.) On the east are the Talkeetna Mountains, made up largely of granitic intrusive rocks believed to be chiefly of Mesozoic age, with a marginal zone of metamorphic sediments. Along the southern flanks of these mountains, drained by Matanuska River, Eocene coal-bearing beds and Jurassic and Cretaceous sediments and volcanic rocks, with possibly some Paleozoic sediments, have been found. These formations, where they lie against the granite, are intensely deformed and faulted. Toward the central part of the Matanuska Valley, however, the Tertiary beds and associated Mesozoic sediments are less disturbed but are cut by many intrusive rocks. Some Tertiary (post-Eocene) volcanic rocks are also found in this province. The metamorphic sediments of the Chugach Mountains, already described, form the southern boundary of the Matanuska Valley.

The geology of the region north of the Talkeetna Mountains is but little known. The bedrock appears to be in part metamorphic sediments, in part little-altered Mesozoic sediments and volcanic rocks.

Some auriferous deposits have been found along the margins of the Talkeetna intrusive rocks. Those developed include the gold placers and lodes of the Willow Creek district. (See pp. 139–152.) Copper deposits are also reported in this province.

The Alaska Range, which bounds the Cook Inlet depression on the west and north, is made up of Paleozoic and Mesozoic sediments thrown up into a broad synclinorium, along the west limb of which there has been profound thrust faulting. These sediments are cut by many large stocks of granite and some of more basic rocks. Though the granitic rocks are of the same type and age as those of the Talkeetna Mountains, they differ in appearing to have brought about but little contact metamorphism. A series of closely folded slates, provisionally assigned to the Paleozoic, occurs along the eastern foot of the Alaska Range. These are believed to form the bedrock of the Yentna placer district, and the occurrence near by of large intrusive masses of granitic rocks suggests a genesis of the auriferous deposits similar to that described for other parts of the Territory. The slates are succeeded by a great complex of Jurassic volcanic rocks, with some sediments (Skwentna group), which are locally auriferous, though they have not yet yielded any commercial deposits. Jurassic slates and graywackes (Tordrillo formation) rest on the volcanic rocks unconformably. Some auriferous mineralization is reported to occur along the contact zones of these slates and the granitic intrusive. The Jurassic sediments have also been recognized along the west arm of the syncline, but here the volcanic rocks (Skwentna group) are absent and the Jurassic sediments rest unconformably on Paleozoic sediments made up of Ordovician, Devonian, and possibly Silurian (Tatina and Tonzona groups) and Carboniferous (?) (Cantwell formation). Some little-disturbed Tertiary coal beds occur along the eastern margin of the range. Tertiary beds are also involved in the profound dislocations along the western base of the range. The Mesozoic beds which form the central part of the synclinorium in the southwestern part of the range do not extend through to the Broad Pass region, where there appear to be only Paleozoic rocks. To the east along the range the recognizable Paleozoic sediments appear also to die out, for the main range in the Valdez Creek region, as already stated, seems to be made up largely of metamorphic schists (Birch Creek?) and granites. The western extension of this schist passes north of the main range in the Nenana basin and here appears to be auriferous, for it forms the bedrock of the Kantishna placer district.

YUKON AND KUSKOKWIM BASINS.

A series of highly metamorphosed sediments of great thickness, called the Birch Creek schist, forms the oldest rocks of the Yukon basin and is probably of pre-Ordovician age. This series is typically made up of quartz-mica schists and mica schists. A common phase is a micaceous quartzite. It also includes crystalline limestones and some greenstone schists which are altered igneous rocks. Gneissoid granites are extensively developed here and there in the schist areas.

The Birch Creek schist is typically developed in the Yukon-Tanana region, where it occupies a broad belt striking westward from the international boundary through to Fairbanks, on Tanana River, forming the country rock of the important placer fields of this province. (See Pl. IV.) North of the Yukon a second belt of schists, of a similar type and probably of the same age, extends westward from the Chandalar placer and lode district into the Koyukuk placer district. Another belt of schists about which little is known but which are probably of the same age occurs in the Kaiyuh Mountains. These mountains lie between the lower Yukon and Innoko districts, which are known to be auriferous, though no commerical placers have been found in this region as yet. This belt probably crosses the Yukon above the mouth of Melozitna River and stretches through the unsurveyed area lying between the Yukon and the Koyukuk. In Fairbanks and Chandalar, as well as in other districts, auriferous quartz veins have been found in the Birch Creek schist. The auriferous mineralization, both in the lode and placer districts, seems to be closely related to granitic intrusive rocks. The age of these granites is probably Mesozoic and is known to be in part Upper Cretaceous.

In the Yukon-Tanana region the Birch Creek schist is succeeded unconformably by many thousands of feet of Paleozoic sediments ranging in age from Ordovician to late Carboniferous. It is beyond the scope of this paper to describe in detail the formations which go to make up this great sequence. Before Upper Devonian time there was a period of diastrophism which deformed the beds previously deposited, and these older formations are known to be locally mineralized and to form the source of some of the placer gold. These older beds are also developed in other parts of the Yukon region and adjacent portions of the Kuskokwim basin.

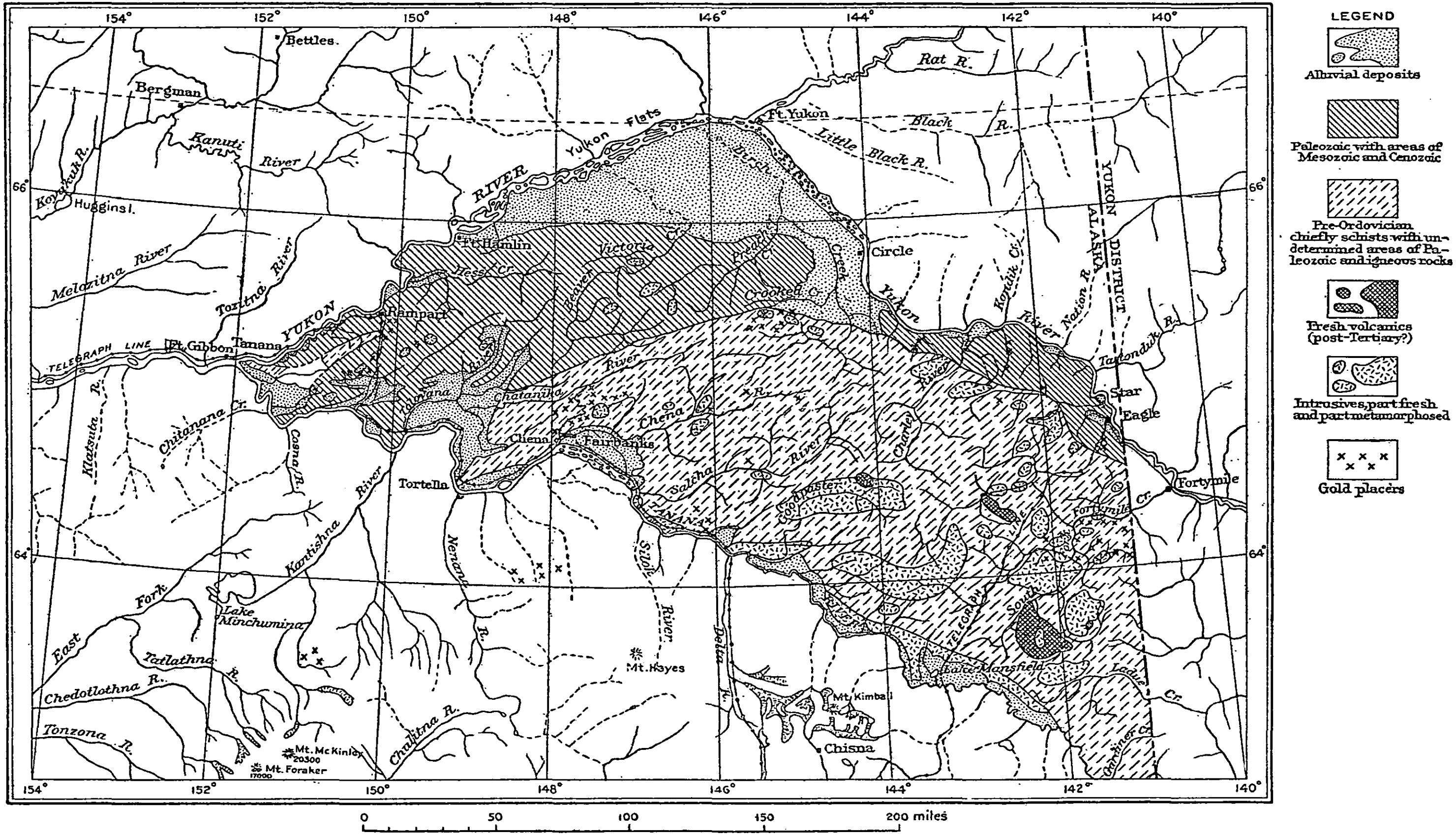
The Mesozoic is represented in the Yukon region by some Triassic limestone and in the Yukon and Kuskokwim basins by widely distributed clastic rocks with some volcanic rocks of Lower Cretaceous or Jurassic age. These rocks are especially well developed in the lower Yukon, Koyukuk, and Kuskokwim valleys and in the Norton Bay region. In the Yukon-Tanana region these Jurassic or Cretaceous rocks do not seem to be loci of important ore deposits, though they are known to be locally mineralized. On the other hand, the gold of the placers of the Innoko-Iditarod region seems to have been derived from contact zones of these Mesozoic sediments and intrusive granites. (See pp. 243–246.) The same is probably true of the Bonanza Creek placers, on Norton Bay.

The only other hard-rock formations of this province are the Eocene and Upper Cretaceous strata, carrying lignitic and subbituminous coal. These beds appear to be widely distributed but do not occur in any large areas. As a rule they do not seem to be metallized, but in the Rampart region some Upper Cretaceous beds have been found which are cut by granite, and near the contact there are some small pyritized quartz veins.

SEWARD PENINSULA.

The Mesozoic sediments stretch westward from the lower Yukon until they lap over on the Paleozoic and older rocks of Seward Peninsula. These Paleozoic rocks constitute a series of varied composition, ranging in age from Cambrian to Carboniferous. They appear to rest on an older series, made up of schists and crystalline limestone and called the Kigluaik group, which may be of pre-Paleozoic age. Granitic stocks have been found in this older group, as well as cutting limestones as young as Carboniferous. There are also some schists, which are altered igneous rocks, infolded with the sediments of different ages. In the northeastern part of the peninsula Mesozoic or Tertiary volcanic rocks are extensively developed. A few small areas of Mesozoic or Tertiary lignitic coal-bearing rocks also occur on Seward Peninsula, as well as Quaternary lava flows.

The placer gold of Seward Peninsula appears to have been derived largely from contact zones of Paleozoic limestones and schists. There are also known occurrences of auriferous mineralization in slates and quartzites. In neither case can the mineralization be directly traced to the influence of intrusive rocks. The peninsula contains, however, some tin deposits, which are directly associated with granite stocks intruded in the Paleozoic sediments.



GEOLOGIC SKETCH MAP OF YUKON-TANANA REGION.

By L. M. Prindle, 1907.

NORTHERN ALASKA.

The geology of northern Alaska is but imperfectly known. On the Kobuk have been found metamorphic sediments, probably representing the same horizons as those of Seward Peninsula, which are, locally at least, auriferous. (See pp. 271–319.) There are also large areas of folded Mesozoic sediments that probably represent the same horizons as those of the lower Yukon.

Near Cape Lisburne occur Carboniferous limestones carrying high-grade coal, some clastic rocks provisionally referred to the Devonian, and a great thickness of folded Jurassic beds, which carry extensive deposits of subbituminous coal. Tertiary beds are also known to occur in this province.

In the section exposed along the Colville and its tributaries Schrader found a central area occupied by rocks of varied lithology and unknown age. South of these are the metamorphic schists of the Koyukuk basin, already described, and to the north are some closely folded and faulted Carboniferous limestones (Lisburne formation) and a heavy conglomerate and slate series of unknown age. North of the mountains these Paleozoic rocks pass underneath gently folded Mesozoic sediments, and these, in turn, under Eocene sediments. Throughout this section there is a striking absence of intrusive and volcanic rocks, and no metal deposits have been found. It is reported by prospectors that crystalline schists occur to the east, near the international boundary, and that some placer gold has been found there.

OUTLINE OF GEOLOGIC HISTORY.

INTRODUCTION.

What is known of the areal distribution of the larger stratigraphic units and their associated metals has been briefly presented in the foregoing pages. In this section will be given an outline of some of the more important events of geologic history which have produced these deposits. Many of these events will be very briefly touched upon, as they have only an indirect bearing on the subject considered, but special emphasis will be laid on those occurrences of the geologic past which are believed to have contributed directly to the formation of ore bodies. It will be impracticable to attempt to correlate all the events of the geologic history of different parts of the Territory; therefore the history will to a certain extent be recounted by districts, taken in order from south to north.

PRE-PALEOZOIC AND PALEOZOIC TIME.

Pacific seaboard.—A number of stratigraphic units, made up chiefly of limestones, cherts, and slates and ranging in age from Silurian to

Carboniferous, have been recognized in the Paleozoic rocks of southeastern Alaska. These represent periods of deposition which were probably interrupted by folding and erosion but need not here be considered in detail. In late Carboniferous or early Triassic time there were in this province extensive extravasations of the basic eruptive rocks, which are now found interbedded with sediments. The metallization all seems to have taken place in post-Paleozoic time.

The broad belt of more or less metamorphosed sediments which skirts the Pacific seaboard from St. Elias westward to Kenai Peninsula (Valdez group) is probably of Paleozoic age or includes some Paleozoic rocks, but the Paleozoic history of this belt is obscure and need not be considered here, as the metal deposits of these rocks are probably of post-Paleozoic age.

Copper-Susitna region.—Records of Paleozoic sedimentation in the Copper-Susitna region are exceedingly meager, for only rocks of Carboniferous age have been definitely recognized. These are chiefly limestones or volcanic rocks, and there is no evidence that they were deformed, intruded, or metallized in pre-Mesozoic time. On the inland slope of the Alaska Range many thousands of feet of Paleozoic rocks were deposited. These have been divided into four groups, ranging in age from Ordovician to Carboniferous. Sedimentation was interrupted by several epochs of folding, followed by erosion. None of these rocks show evidence of mineralization in Paleozoic time, and their earlier geologic history is therefore not pertinent to this discussion.

Yukon and Kuskokwim basins.—Little is known of the sequence of events by which the Birch Creek schist—the oldest formation of the Yukon basin—was formed, but it consists certainly for the most part of sediments deposited in early Paleozoic or pre-Paleozoic time. After the deposition and induration of these sediments they were invaded by igneous rocks of various types and still later, but probably in pre-Ordovician time, they were intensely deformed while under a heavy rock cover. Before this deformation and possibly accompanying or immediately after the igneous intrusions, quartz veins were injected, some of which appear to have been metalliferous. These veins were folded and broken by the subsequent deformation and now occur chiefly as stringers, thin lenses, and vugs, which constitute the oldest system of veining in the region and do not seem to be of economic importance. Uplift and a long period of erosion of this complex seem to have taken place before the deposition of the oldest known Paleozoic formation of this field, which has been assigned to the Ordovician. The important auriferous mineralization of the Birch Creek schist, as will be shown below, is believed to have taken place in Mesozoic time.

The sequence of geologic events in the Yukon region during Paleozoic time up to the Middle Devonian is far from being established. It is known that there were long periods of deposition interrupted by epochs of erosion, and the resulting strata have been divided into several rock groups, including some which are known to be Ordovician, some Silurian, and some probably Lower Devonian. There appears to have been no notable metallization of these rocks during these periods of diastrophism. The Middle Devonian is characterized by a siliceous limestone which is very widely distributed in Alaska and which in the Yukon-Tanana region is associated with a great thickness of volcanic rocks, chiefly of a basic character, which at a later time were locally mineralized.

It is probable that after the deposition of the Middle Devonian beds there were extensive crustal disturbances, and these may have been accompanied by some quartz veining. The later Paleozoic history of the Yukon is of no significance to the problems here under discussion, and it will suffice to state that in Upper Devonian and Carboniferous time there were two periods of erosion, but that there appears to have been no interruption to sedimentation from Paleozoic to early Mesozoic time.

Seward Peninsula.—A Cambrian limestone is the lowest formation in Seward Peninsula whose age has been determined, but some schists and limestones have been found that may be older. In general, the known Paleozoic of the peninsula is represented by vast thicknesses of limestones ranging in age from Upper Cambrian to Carboniferous. Intercalated with some of these are schists which are in part known to be of igneous origin and various clastic rocks. The whole sequence has been so intensely deformed as to defy subdivision except after most detailed investigation.

An injection of quartz veins took place previous to this deformation, and these are now found as small irregular lenses and stringers. Many of these veins are metallized and some are said to be gold bearing. It is an open question whether the placer gold was derived to any extent from the older system of veining, or whether its source is largely in the younger unsheared veins referred to below. This latter epoch of auriferous mineralization is provisionally assigned to the Mesozoic, as is also the mineralization which produced the deposits of cassiterite, galena, etc., which are all more or less intimately associated with granites that are probably of post-Carboniferous age.

Northern Alaska.—Paleozoic rocks, in part of Carboniferous age, occur in the Endicott Mountains of northern Alaska, but the sequence of geologic events in this region has not been definitely determined. A series of schists, probably of Birch Creek age, occurs along the northern base of the Endicott Mountains, and probably has had the same geologic history. Similar rocks occur in the Kobuk Valley. The fact that there appears to have been no intrusion of igneous rocks or of metallized quartz veins in the Paleozoic areas of the Endicott Mountains is for the present discussion the most noteworthy fact in the geologic history of this region.

MESOZOIC TIME.

Economic importance.—From the standpoint of one interested in ore deposits, the Mesozoic was the most important era in the geologic history of Alaska, for nearly all the metallization which has formed commercial deposits and to which age assignment can be made falls within it. The time of most intense and widespread metallization can probably be still further limited to the Jurassic or Cretaceous and was thus synchronous with the mineralization which produced the valuable deposits of California and other parts of the western Cordillera. Therefore most of Alaska's metallic deposits belong to the same metallogenetic province as those of the western United States. It is not to be understood by this that the ore deposits are in any sense confined to Mesozoic horizons, for this is far from being the case. In fact, except in southeastern Alaska and in a few other districts the metalliferous deposits occur chiefly in pre-Mesozoic rocks. The mineralization which caused ore deposits took place, however, in Mesozoic time.

Stratigraphic sequence.—Sedimentary and volcanic rocks of Triassic age are widely distributed in Alaska. In general the Triassic appears to have been a period of limestone deposition, with possibly some local volcanic outbursts. So far as known, there are only a few localities where ore deposits occur with Triassic rocks. The most noteworthy of these are in the Copper River region, where copper deposits occur in the Chitistone limestone, of Triassic age, and in an older series of ancient lava flows (Nikolai greenstone), of either Triassic or Paleozoic age.

The Orca group, of Prince William Sound, is perhaps Triassic, but it is not possible now to speak with precision in regard to its age. It can be subdivided into a lower member, in which ancient volcanic rocks dominate, with some clastic rocks, and an upper member, in which slates and graywackes dominate, with some volcanic rocks. The lithology of these rocks is very different from that of the Triassic rocks of other parts of Alaska, where calcareous deposits are the rule and the clastic and volcanic rocks are the exception. Sedimentation was closed at about the end of Triassic time by a widespread crustal movement, followed by erosion.

During Jurassic time deposition of fragmental material took place over much of Alaska. Many thousands of feet of sandstones and argillites, with some volcanic rocks, were laid down, and sedimentation was probably interrupted by periods of erosion. The Jurassic history is complex and need not be considered for the purposes of this report. One phase of it which deserves mention, however, is the volcanic outburst in the southwestern part of the Alaska Range and in the Alaska Peninsula. The rocks of this epoch are locally auriferous, though they have not yet been the source of any large amount of gold. In late Jurassic and early Cretaceous time extensive deposits of argillaceous and arenaceous sediments were accumulated over much of Alaska, and these were subsequently folded and more or less altered. These Jurassic and Cretaceous sediments are important loci of gold deposits in southeastern Alaska and elsewhere. They appear to form the youngest beds which have yielded any commercial ore bodies, though some evidence of mineralization has been found in rocks as young as the Upper Cretaceous.

Intrusive rocks.—The genesis of most of the Alaskan ore bodies is more or less directly traceable to the influence of intrusions which took place during Mesozoic time. During this period of intrusion probably most of Alaska south of the Endicott Mountains was injected by igneous rocks. The intrusions began in early Jurassic time, possibly in some parts of the region in Triassic or even in late Paleozoic time, and culminated during Lower Cretaceous time, but continued in some places into the Upper Cretaceous. This epoch of volcanism followed and accompanied crustal movements which were continental in their effect and as a result of which many of the main structural lines were established. Along these lines, however, some movements took place later.

The great batholiths of the Coast Range of southeastern Alaska were probably intruded during Jurassic and Cretaceous time. The northwesterly extension of this same belt of intrusive rocks carries them into the Alaska Range, where large stocks of igneous rocks are common. All these intrusive rocks show the same lithologic facies, ranging from granites to diorites in composition. Rocks of the same varieties and of approximately the same age of intrusion are found in the batholiths of the Talkeetna Mountains, north of Cook Inlet. Granitic rocks are abundantly developed in the Iliamna region, some of which, however, may be of Paleozoic age. Mesozoic granitic intrusive rocks are also found in the lower Yukon and Kuskokwim basins and in the Norton Bay region. The age of the granites of Seward Peninsula is unknown, but they are, in part at least, later than rocks known to be of Mississippian age and are probably Mesozoic. It is impossible to speak with precision as to the age of the granitic rocks of the upper Yukon basin. At one locality they cut Upper Cretaceous rocks, and the presumption is fair that they are in greater part of Mesozoic age and to be correlated with those of the other parts of Alaska whose age has been more definitely fixed.

In addition to the granular intrusive rocks, dikes of similar chemical composition but differing mineralogically occur in many parts of Alaska and seem to belong to the same period of intrusion. This period of intrusion was probably long continued in some parts of the province, where there were probably several series of intrusions, the later ones being injected after the first had been solidified and fractured. Thus, in southeastern Alaska the main granitic masses were fractured and injected by acidic aplitic dikes, which represent the last phase of this epoch of volcanism. Similarly, the metalliferous quartz veins were introduced after the igneous intrusives—in fact, after these were solidified and fractured. The genesis of the quartz veins is therefore probably related closely to that of the granite.

The wide distribution of the metalliferous deposits in the contact zones of the igneous and country rock has already been pointed out. The gold and copper deposits of southeastern Alaska and of the Iliamna region, the gold deposits of the Nizina, Yukon-Tanana, Chistochina, Yentna, Willow Creek, Koyukuk-Chandalar, Innoko-Iditarod, and possibly those of Prince William Sound and Kenai Peninsula, all appear to be genetically related to the Mesozoic intrusive rocks. In fact, the auriferous deposits of Seward Peninsula are the only ones for which there does not seem to be some rather clear evidence that their mineralization is genetically related to igneous rocks, and in most of the auriferous districts there is good reason to believe that the intrusions took place in Mesozoic time.

TERTIARY AND QUATERNARY TIME.

The geologic history of Tertiary and later time bears only indirectly on the occurrence of metalliferous lodes. The Eocene was essentially an epoch of lacustrine and fluviatile conditions, when extensive deposits of coal accumulated. This was followed by a period of diastrophism, in which most of the folding of the rock strata now visible took place and was accompanied by some basic intrusion and extravasation of volcanic rocks. So far as known, there was no mineralization during this period of deformation. It is, however, important in the consideration of the distribution of the metals, because it determined in many districts the attitude and areal distribution of the beds with which the metals are associated.

Late Tertiary and Quaternary history is replete with geologic interest but has little bearing on the present discussion. Its later phases had to do with the accumulation of the alluvium in which the gold placers occur. In the Quaternary, too, occurred an epoch of glaciation which removed from the mountains of the coastal system, and to a less extent from those of northern Alaska, the débris resulting from the previous weathering, and in some places deeply channeled the drainage courses. This phase of the geologic history has one important bearing on the lode mining, inasmuch as the glacial ice, in part at least, removed the upper zone of rock material in which the secondarily enriched mineral deposits should be found. It is probably safe to conclude that in most places where glacial scouring was active no deposits which have been secondarily enriched by surface waters occur;[1] in any event, no such deposits have yet been recognized in Alaska except at very shallow depths.

THE ORE DEPOSITS.

INTRODUCTION.

For the purpose of systematic description the lode deposits will be thrown into several large groups, each of which will be made to include all the deposits chiefly valuable for a certain metal. Within each group further subdivisions will be made, based primarily on geologic association and only secondarily on considerations of mineralogy and genesis. This rough classification will, it is believed, serve the present purposes and will accord with the limitations placed on this discussion, both as to length and as to precision of data used. It will, at least, have the merit of making no pretense at anything except immediate utility and will leave a clear field for the formulating of a genetic scheme of classification by those who have made a more exhausitve study of the subject than the writer has.

GOLD.

OUTLINE.

The gold-bearing lodes which are more or less closely associated with intrusive rocks form by far the most important group of auriferous deposits in Alaska, and these intrusives are, as has been shown, chiefly if not wholly of Mesozoic age. A second group of gold deposits which for the present will be regarded as distinct, comprises those of Seward Peninsula, for these are not known to have a genetic relation to intrusive rocks. Each of these larger groups can be further subdivided in accordance with the country rock in which they occur and the character of the openings in which they were deposited. Thus, those associated with igneous rocks will be subdivided according as they occur in the intruded or in the intrusive rock. Each of these subdivisions can be further separated into fissure veins, impregnated zones, and stockwork deposits. It will be evident from what follows that there are some mixed types of deposits which it will be difficult to fit into this scheme of classification.

DEPOSITS ASSOCIATED WITH INTRUSIVE ROCKS.

GENERAL STATEMENT.

The auriferous deposits of southeastern Alaska, as already pointed out, furnish the best examples of the close association between Mesozoic intrusive rocks and ore bodies. This fact is well illustrated

[1] It will be evident that other factors, such as temperature of water, and hence climate, presence or absence of vegetation, also enter into the problems connected with secondary enrichment, but these will not be considered here.

by the geologic map of this province (Pl. II, p. 46), on which the localities of auriferous ore bodies are indicated. These ore bodies, while they bear a close relation to the intrusive rocks, do not occur in the zone of igneous metamorphism but in the adjacent sediments, which are less highly altered. This seems to be true of all the deposits. In those lodes which lie close to or at the contact of intrusive rocks there is as a rule no great amount of igneous metamorphism.

LODE DEPOSITS IN THE INTRUDED ROCKS.

The best-developed auriferous deposits are those of the Juneau gold belt, which, according to Spencer,[1] occur in a well-defined lode system that skirts the mainland both north and south of Juneau. The country rock is chiefly argillite, with some igneous rocks, which can be collectively classed as greenstones of late Paleozoic or Mesozoic age and lie close to, though not in contact with, the Coast Range batholith.

The dominant ores are those carrying free gold and iron pyrite, but pyrrhotite, chalcopyrite, galena, sphalerite, arsenopyrite, stibnite,

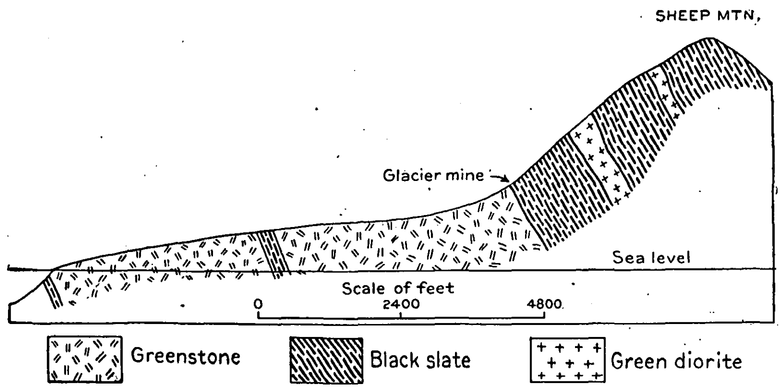


FIGURE 1.—Profile section from mouth of Sheep Creek to Sheep Mountain, Juneau district, showing locus of auriferous mineralization. By A. C. Spencer, 1903.

tetrahedrite, molybdenite, pyrargyrite, and magnetite have also been found. Quartz is the chief gangue mineral, but calcite and other minerals also occur.

Spencer recognizes two types of ore bodies—(1) the veins, which include the mineral aggregates deposited in fractures of the country rock, and (2) the impregnated zones, in which the metallic minerals are disseminated, more or less irregularly, through masses of the country rock. Some deposits, as that of the Treadwell (see pp. 67–69), appear to combine both types of ore bodies. These general types have also been recognized in other parts of Alaska.

A good example of the vein deposits is that on Sheep Creek, near Juneau. Here the country rock is a part of the slate-greenstone

[1] Spencer, A. C., The Juneau gold belt, Alaska: Bull. U. S. Geol. Survey No. 287, 1906, pp. 21-137.

series typical of the Juneau belt, which is cut by diorite dikes. The ore bodies occur at a slate-greenstone contact near the intrusive diorite. In figure 1 the locus of mineralization is indicated by the position of the Glacier mine. At this locality three parallel veins occur in the slates, near the greenstone contact (fig. 2), and these veins, with a number of others lying farther from the greenstone contact, occupy a mineralized zone some 400 feet wide. The fissures are in general parallel to the cleavage, but in places they cut across it.

Across the divide from Sheep Creek, to the northwest, in the valley of Gold Creek, the same general geologic conditions for the occurrence of the ore bodies prevail. The deposits all occur in the greenstone-slate series near contacts with the intrusive rocks. Here the principal mineralization has produced stringer leads which are complex networks of quartz veins following two systems of fractures and constituting a deposit of the impregnated-zone type. Many of these lodes occur directly at the contact of diorite and slate, the diorite being more or less altered.

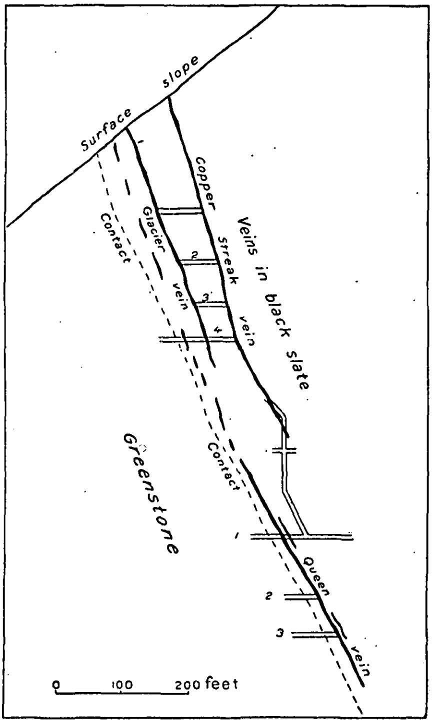


FIGURE 2.—Generalized cross section of Silver Queen and Glacier mines, Juneau district, illustrating the relation of the zone of mineralization to the slate-greenstone contact. By A. C. Spencer, 1903.

In addition to the deposits of the mainland belt some mineralization has been found in the greenstones of the western part of Douglas Island. Here the country rock consists of slates and greenstones and the ore bodies consist of impregnated zones of fracture. Spencer[1] notes that pyrite is the chief metallic mineral in these deposits, but galena, sphalerite, and chalcopyrite have also been found. Albite and rutile occur as gangue minerals.

Auriferous deposits have also been found in the argillite and greenstones which skirt the mainland and adjacent islands west of the granites of the Coast Range in the Ketchikan district, south of Juneau. Here some small fissure veins have been found, but deposits of the disseminated type appear to dominate and have yielded but

[1] Spencer, A. C., The Juneau gold belt: Bull. U. S. Geol. Survey No. 287, 1906, pp. 92–93.

few commercial ore bodies. These deposits occur in rocks which lie adjacent to areas affected by contact metamorphism due to granite intrusion. They include some auriferous quartz veins, but the prevailing type of deposit is the mineralized fracture zone. These zones occur especially in the greenstone schists and are characterized by an abundance of iron pyrite with but little gangue. Their gold values are usually low, but some of them carry lenses and vugs of quartz very rich in free gold.

Deposits of the fissure-vein type have also been found in many parts of the Ketchikan district[1] but so far have yielded no very large or very rich ore bodies. Most of these occur in or are intimately associated with porphyry dikes and will be considered later (pp. 69–70).

The auriferous quartz veins of the Sitka region, described by Mr. Knopf on page 98 of this volume, cut a graywacke series, which is probably of Mesozoic age. No intrusive rocks occur in the immediate vicinity of the ore bodies, but a large stock of granite is known to lie a few miles to the east. Auriferous veins have also been found at a number of places on Prince William Sound,[2] notably at Port Valdez and McKinley Lake. Here again the association with intrusive rocks is not definitely established. On Port Valdez the bedrock consists of a closely folded sequence of slate and graywackes belonging to the Valdez group. The veins appear to follow a well-defined system of fissuring. At the Cliff mine, which is the only deposit examined, the ore is blue quartz carrying much finely disseminated pyrite with minute quantities of arsenopyrite and high values in free gold. Some of the veins have been crushed and recemented by quartz.

The gold-bearing veins of Kenai Peninsula[3] appear to be similar in character. They are quartz veins carrying pyrite, arsenopyrite, and free gold. At one locality some telluride has been found.

Mr. Moffit's description of the Valdez Creek placers (pp. 119–127), in the upper Susitna region, and of the Chistochina placers, both of which occur in argillites, also indicates a close relation between the bedrock source of the gold and the granitic intrusive rocks. To this type of deposit should probably also be added the deposits of Bonanza Creek,[4] near the eastern shore of Norton Bay, where, however, no gold has yet been found in the bedrock.

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[1] Brooks, A. H., Preliminary report on the Ketchikan district, Alaska: Prof. Paper U. S. Geol. Survey No. 1, 1902. Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts: Bull. U. S. Geol. Survey No. 347, 1908.

[2] Grant, U. S., and Higgins, D. F., Reconnaissance of the geology and mineral resources of Prince William Sound, Alaska: Bull. U. S. Geol. Survey No. 443, 1910.

[3] Grant, U. S., and Higgins, D. F., Preliminary report on the mineral resources of the southern part of Kenai Peninsula: Bull. U. S. Geol. Survey No. 442, 1910, pp. 166–178.

[4] Smith, P. S., and Eakin, H. M., A geologic reconnaissance in southeastern Seward Peninsula and the Norton Bay-Nulato region: Bull. U. S. Geol. Survey No. 449, 1911.

In the Yukon-Tanana region as a whole, but more especially in the Fairbanks district, there appears to be a close genetic relation between the gold deposits and the granite intrusive rocks. (See Pl. IV, p. 52.) At Fairbanks, where some work has been done on lodes, two systems of quartz veining have been recognized, both of which cut the Birch Creek schist. In addition to these, quartz stringers occur in the laminations of the schists and have been involved in the folding. The crosscutting quartz veins of the older generation appear to be larger than those of the later system, but while they carry some iron pyrite, the gold values appear to be low. After their introduction these veins were brecciated [1] and the bedrock was again fractured. The openings thus formed were impregnated by mineral-bearing solutions. In this way the older system of veins was enriched and some new veins were formed. The metal contents of the deposits due to the second period of mineralization are free gold, pyrite, stibnite, arsenopyrite, galena, and sphalerite. Quartz is the chief gangue mineral, with some calcite and locally orthoclase, calcite, albite, and tourmaline. The general distribution of the quartz veins indicates that there is a mineralized zone which parallels the main structures of the country rock but which is not very well defined (fig. 3). There have been some recent lode developments in the Chandalar placer district, north of the Yukon, where the conditions are probably similar to those at Fairbanks and where the deposits occur in close relation to intrusive rocks.

In addition to the fissure veins the Fairbanks district contains lode deposits which are probably comparable to those of the Juneau district described as mineralized zones. These are zones of fracture in the schists which have been permeated by mineral-bearing solutions. They are characterized by networks of small metalliferous quartz veins, forming stringer-lead deposits. In some places the quartz veining is only a very subordinate phenomenon, the main mass of the deposit being made up of pyritized schist carrying some gold. Only a few assays have been made on this type of deposit, but these indicate that the gold values are low. A deposit of this kind in the Bonnifield district is described by Mr. Capps on page 230. Here the country rock appears to be an altered and highly schistose rhyolite and not a sediment, as is the case in the Fairbanks district. It also seems probable that the gold of the placers of Willow Creek, in the Susitna basin (see pp. 145–146), has been derived from similar mineralized zones in a crystalline schist. This occurrence appears to be of a somewhat different type from those previously described, for it seems to lie within the zone of igneous metamorphism.

[1] Prindle, L. M., Auriferous quartz veins of the Fairbanks district: Bull. U. S. Geol. Survey No. 379, 1910, pp. 210-229.

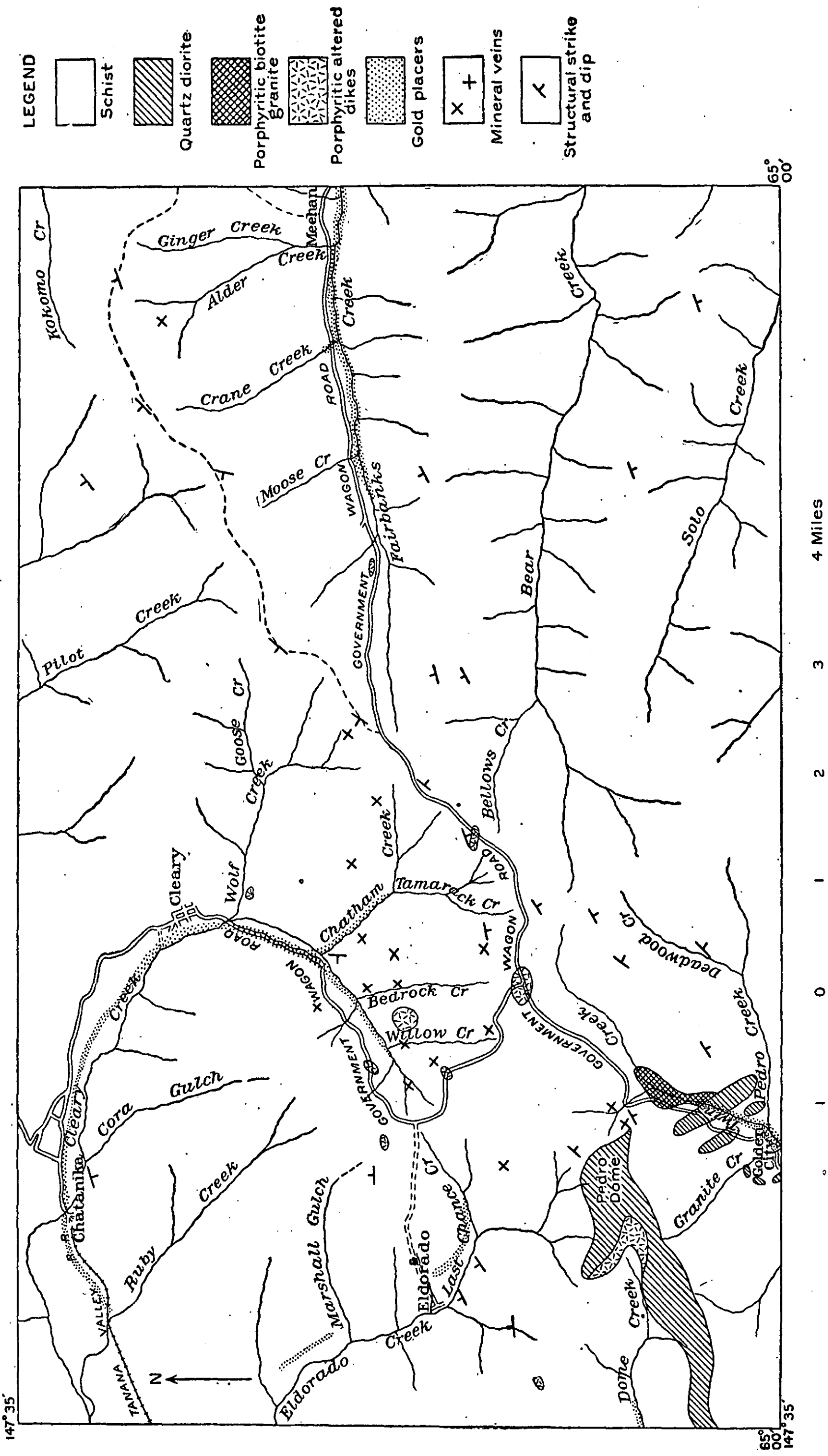


FIGURE 3.—Geologic sketch map of auriferous lodes in Fairbanks district. By L. M. Prindle, 1909.

As a general rule, the mineralized zones in the bedrock appear to occur in the schists, where the movements have not brought about notable open spacings but have formed crushed zones subsequently permeated by the mineral-bearing solutions. Such disseminated deposits seem to be more favorable to the formation of placers than where the ores occur in better-defined fissures. Where the physical character of the country rock has induced fractures with open spaces rather than shear zones, deposits of the fissure-vein type are more likely to be formed.

Auriferous veins that occur in crystalline limestones, usually near the contact with intrusive rocks, form another class of ore bodies which, however, differ from some of the silver-lead deposits to be described below only in the fact that they are valuable chiefly for their gold contents. This type of deposit is represented in southeastern Alaska by a number of ore bodies which have been more or less developed on Prince of Wales Island.[1] They occur typically in brecciated zones in crystalline and semicrystalline limestones, the openings thus formed having been penetrated by the mineral-bearing solutions and quartz and calcite, together with free gold, pyrite, chalcopyrite, tetrahedrite, galena, sphalerite, and arsenopyrite. These minerals have to a certain extent replaced the limestone, a fact which gives the ore bodies indefinite boundaries. Usually the values are distributed in shoots within the brecciated zone. Moffit and Knopf [2] have described the Royal Development Co.'s property at Jacksina Creek, in the Nabesna basin, as a mineralized contact zone between crystalline limestone and diorite. The entire mass has been sheared and heavily pyritized. At the surface at least it carries free gold, but it is not known what the form of the gold is below the zone of weathering.

Nearly all the gold deposits which have been described occur in rocks of sedimentary origin which have been subject to the influence of granitic intrusive rocks. In southwestern Alaska there is evidence of auriferous mineralization of volcanic rocks at and near the contact of granitic intrusives. Spurr [3] has described an example of this form of mineralization in a natural exposure on Skwentna River, north of Cook Inlet. The geologic relations are represented diagrammatically in figure 4. The mineralized area in the basalt along the granitic contacts in this and other localities contains pyrite, chalcopyrite, and galena, and assays show the presence of gold.

[1] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: Bull. U. S. Geol. Survey No. 347, 1908, pp. 81-82, 166-177. Brooks, A. H., Preliminary report on the Ketchikan mining district, Alaska: Prof. Paper U. S. Geol. Survey No. 1, 1902, pp. 54, 77-88.

[2] Moffit, F. H., and Knopf, Adolph, Mineral resources of the Nabesna-White River district, Alaska, Bull. U. S. Geol. Survey No. 417, 1910, p. 58.

[3] Spurr, J. E., A reconnaissance in southwestern Alaska: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 111-112, 259.

Evidence of mineralization in volcanic rocks of the same age has been found in other parts of this region.[1]

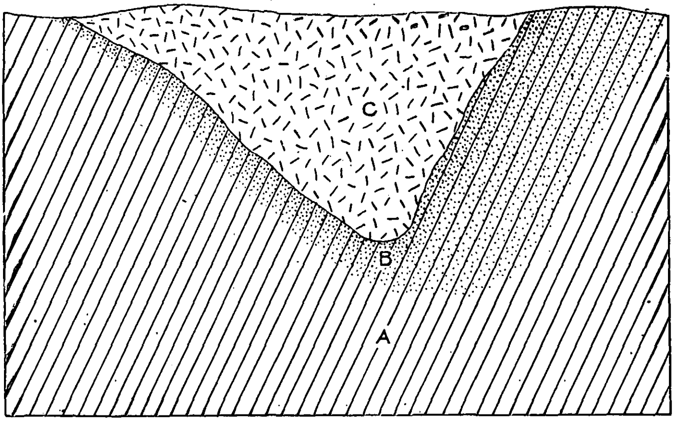


FIGURE 4.—Diagrammatic section of exposure in canyon of Skwentna River, illustrating mineralization in basalt along contact of granite dike. By J. E. Spurr, 1898. A, Ancient basalts; B, same, impregnated by metallic sulphides; C, intrusive granite.

The only developed lode in southwestern Alaska is the Apollo mine, on Unga Island. This deposit has been described by Becker [2] and others as occupying a zone of fracture in a country rock of dacite and andesite. Becker considered the volcanic rocks as of Miocene or post-Miocene age, but Atwood has called this determination in question and believes that they are certainly pre-Miocene and may be Mesozoic. Atwood also reports some dacite dikes on Unga Island, though none were observed in the immediate vicinity of the ore body. The metallic minerals of the deposit are free gold, pyrite, chalcopyrite, galena, zinc blende, and native copper. Other deposits of similar character have been noted in the neighborhood. There is no direct evidence of the influence of intrusives on this mineralization.

Some auriferous mineralization [3] has also been noted on Unalaska Island, at the east end of the Aleutian chain. Here the bedrock consists of andesitic volcanic rocks, whose age is unknown but is probably Mesozoic. A large granitic stock lies near this occurrence, and there is evidence that it has had some mineralizing influence.[4]

LODE DEPOSITS IN THE INTRUSIVE ROCKS.

The lode deposits in the intrusive rocks include those in shear zones in massive granite or diorite and also mineralized dikes. A

[1] Brooks, A. H., The Mount McKinley region, Alaska: Prof. Paper U. S. Geol. Survey No. 70, 1911, pp. 163-164.

[2] Becker, G. F., A reconnaissance of the gold fields of southern Alaska: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 12, 83-85. Martin, G. C., Gold deposits of the Shumagin Islands: Bull. U. S. Geol. Survey No. 259, 1905, pp. 100-101. Atwood, W. W., Mineral resources of southwestern Alaska: Bull. U. S. Geol. Survey No. 379, 1909, pp. 149-151.

[3] Collier, A. J., Auriferous quartz veins on Unalaska Island: Bull. U. S. Geol. Survey No. 259, 1905, pp. 102-103.

[4] Jaggar, T. A., Journal of the Technology expedition to the Aleutian Islands in 1907: Reprinted from Tech. Review, vol. 10, No. 1, pp. 17-19.

good example of the first type is found in the Kensington lode, in the Berners Bay region of southeastern Alaska. According to Knopf[1] the ore body consists of an irregular mass of crushed diorite, marking a zone of movement within massive diorite walls (fig. 5). This fracture zone has been gashed by a multitude of quartz stringers, forming a stockwork deposit. It carries pyrite and, in at least one place, a little galena. More or less alteration of the diorite walls of the lode was noted. The outcrop of the Kensington lode is about half a mile east of a slate-graywacke series of Jurassic or Cretaceous age into which the diorite is intrusive. According to Knopf there are also well-defined fissure veins within the diorite of the Berners Bay region.

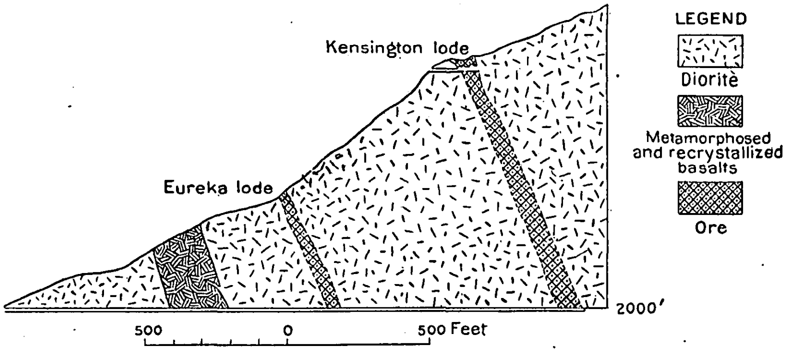


FIGURE 5.—Diagrammatic section along Kensington tunnel, Berners Bay, showing auriferous lode in diorite. By Adolph Knopf, 1909.

The ore deposits of the Treadwell group of mines also belong to this type of deposit, but the relations are not as simple as those at the Kensington. These mines, which are located on Douglas Island, near Juneau, and have produced over $40,000,000 worth of gold, form the largest mining enterprise in Alaska and one of the largest in the world, and their ore deposits will therefore be described in some detail. The following account is abstracted from Spencer's report:[2]

The ore bodies consist essentially of fractured and mineralized diorite dikes, which have penetrated a black slate parallel with and close to a greenstone contact (fig. 6). The greenstones appear to be altered volcanic rocks, and they, with the slates, constitute a part of the series which forms the country rock of much of the Juneau gold belt and is now regarded as probably of Jurassic or Cretaceous age. The fracturing of the diorite dikes has given opportunity for the mineralizing solutions to penetrate, and these have formed an intricate and irregular network of veinlets which can be designated as stringer leads. In addition to this, the ore-bearing solutions have permeated

[1] Knopf, Adolph, Geology of the Berners Bay region, Alaska: Bull. U. S. Geol. Survey No. 446, 1911, pp. 40–42.

[2] Spencer, A. C., The Juneau gold belt: Bull. U. S. Geol. Survey No. 287, 1906, pp. 88–116.

the diorite dikes, which have been largely altered to a mass of secondary minerals and vein matter. This mineralization has been traced by mine workings for almost 3,500 feet, with an extreme width of 400 feet. A depth of 1,600 feet has been attained without any notable change in values.

The dominating metallic minerals are free gold and pyrite, with considerable pyrrhotite and magnetite. In addition to these, chalcopyrite, galena, sphalerite, native arsenic, realgar, and orpiment have been found. Much of the gold is free, as high as 75 per cent of the assay value having been recovered. The important gangue minerals are feldspar, calcite, and quartz, with some rutile. Some of the original minerals of the diorite, such as feldspar, hornblende, and mica, are still present. Epidote, an alteration product of the primary minerals, is also found.

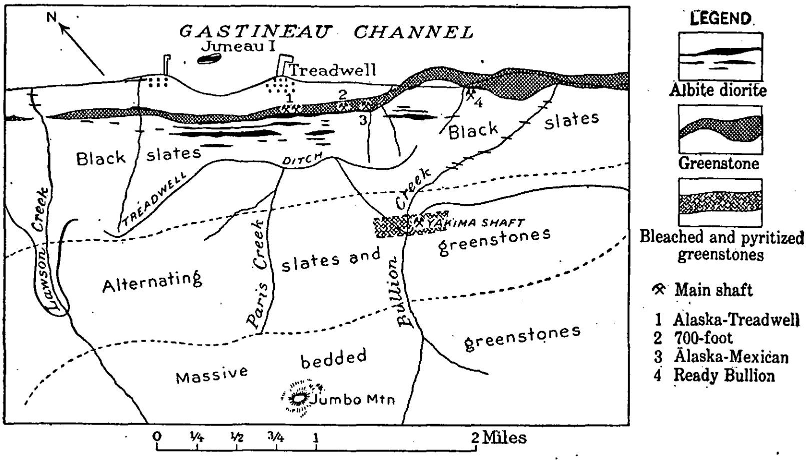


FIGURE 6.—Geologic sketch map of northwest end of Douglas Island. By A. C. Spencer, 1903.

The Treadwell ore bodies in their mode of origin and form of occurrence do not differ from some of the other deposits of the Juneau gold belt. Spencer has described the diorite adjacent to some of the lode deposits on Gold Creek as altered and more or less mineralized. It appears that in the Treadwell deposits the entire diorite mass was crushed, and the fractures thus formed gave opportunity for the mineral-bearing solutions to circulate, and the process continued until the whole dike was impregnated, while in deposits of the Kensington type the mineralization followed zones of crushing included within walls of massive igneous rocks.

Some auriferous veins have been found in a massive country rock of granite near Karta Lake, on Prince of Wales Island, in the Ketchikan district.[1] These veins follow fissures with well-defined walls and have a marked regularity in direction and thickness. In some places

[1] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: Bull. U. S. Geol. Survey No. 347, 1908, pp. 164-166.

diabase dikes have penetrated the fissures and have subsequently been fractured, and the auriferous quartz filling has been deposited along the spaces thus formed. The metallic vein minerals are free gold, pyrite, galena, and chalcopyrite, with a gangue of quartz, calcite, and possibly sericite.

The auriferous lodes of the Willow Creek region, north of Cook Inlet, described by Mr. Katz on pages 144–146, also belong to this type of deposit. These occur as fillings in what appear to be well-defined fissures in a quartz diorite country rock. Martin and Katz [1] have described a mineralized zone occurring within a granitic country rock near Cottonwood Bay, on Cook Inlet. This is described as a zone of shattering in a granite mass along which pyritiferous quartz veins have been deposited. Low gold values are reported. A mass of greenstone occurs near the ore body, and the granite is locally intruded by porphyry dikes.

At Orange Hill, in the Nabesna River basin, tributary to the Tanana, some auriferous mineralization has been found in a quartz diorite mass.[2] At this locality the diorite is cut by many small quartz stringers, some of them carrying pyrite and a few molybdenite. A similar deposit has been noted on Monte Cristo Creek, in the same region, and to the east on Beaver Creek, a tributary of upper White River. Several auriferous lodes have been found in the basin of Eureka Creek, also tributary to the White, which appear to be mineralized zones of fractures in a silicified feldspar porphyry.

The presence of auriferous deposits in granites and granodiorites is inferred from the distribution of placer gold in several districts. Thus the gold of the placers of Hill Creek, in the Fairbanks district, appears to have been derived from a mineralized zone in the margin of a granite stock. Mr. Maddren's description of the placers of the Iditarod (pp. 245–270) suggests that the gold was in part derived from a granite bedrock source. The writer [3] has also noted the occurrence of a mineralized zone in a granite 15 miles below Robertson River, on the north side of the Tanana Valley. Here both gold and pyrite were found disseminated in a brecciated zone about 10 feet wide, traversing a granite mass.

Mineralized dikes are not uncommon in many districts and some of these carry gold values. Such deposits have been found at the Sea Level mine and near Hollis, in the Ketchikan district.[4] Here the country rock is chiefly greenstone and calcareous schist (Mesozoic

[1] Martin, G. C., and Katz, F. J., Outline of geology and mineral resources of the Iliamna and Clark lakes region: Bull. U. S. Geol. Survey No. 442, 1910, p. 194.

[2] Moffit, F. H., and Knopf, Adolph, Mineral resources of the Nabesna-White River district: Bull. U. S. Geol. Survey No. 417, 1910, pp. 58–60.

[3] Brooks, A. H., Reconnaissance in the Tanana and White River basins, Alaska, in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, p. 487.

[4] Brooks, A. H., Preliminary report on the Ketchikan mining district, Alaska: Prof. Paper U. S. Geol. Survey No. 1, 1902, pp. 66–67, 91–93. Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: Bull. U. S. Geol. Survey No. 347, 1908, pp. 144–146, 160–161.

or late Paleozoic), which have been crosscut by porphyry dikes. These dikes have, in turn, been fractured and invaded by mineral-bearing solutions that deposited pyrite, galena, sphalerite, with some native gold, and quartz and a little muscovite as gangue minerals. The dike rock itself has in places been heavily mineralized.

At the Crackerjack mine, near Hollis, the country rock is slate, more or less graphitic, which has been invaded by a porphyry dike. The ore body lies adjacent to this dike, but the dike itself has been epidotized and pyritized. The ore carries pyrite, galena, sphalerite, and an undetermined black antimony or bismuth mineral, with quartz and a little calcite as gangue minerals. In both localities there are deposits of similar types which are not so intimately associated with the dikes.

A pyritized dike rock, which is associated with an auriferous lode deposit in the Moose Pass district of Kenai Peninsula, has been described by Grant and Higgins.[1] The dike is made up of a fine-grained aggregate of plagioclase, quartz, mica, and probably orthoclase, with scattered crystals of arsenopyrite. The mica is of a light-green color and is secondary after the feldspar. Maddren[2] has noted pyritized dikes which carry gold in association with quartz veins in the Innoko district. In this field intrusive granites are known to be close at hand.

LODES OF SEWARD PENINSULA.

The gold-bearing lodes of Seward Peninsula are here described separately because it can not be proved that they bear a genetic relation to intrusive rocks as do most of those already described. Smith,[3] to be sure, considers, that the intrusive granitic rocks of the Kigluaik Mountains were injected at the same time as some of the quartz veins of the Solomon-Casadepaga region. He also cites the presence of tourmaline in many of the rocks as evidence that granitic intrusives may underlie areas where they do not outcrop. The facts remain, however, that in those parts of the peninsula which, from the evidence of placer gold, must have been heavily mineralized no granitic intrusive rocks have been found and that no auriferous deposits have been found in the regions which are known to have been intruded by granite. Moreover, the type of mineralization in areas that have been invaded by granite has not produced ore bodies valuable for gold but deposits carrying tin, tungsten, galena, etc., and these (see pp. 87–90) appear to differ essentially from the veins and mineralized zones which have yielded the placer gold. It is therefore at least an open question whether this auriferous mineralization bears any direct genetic relation to the granitic intrusives.

[1] Grant, U. S., and Higgins, D. F., Preliminary report on the mineral resources of the southern part of Kenai Peninsula: Bull. U. S. Geol. Survey No. 442, 1910, pp. 171–172.

[2] Maddren, A. G., The Innoko gold placer district: Bull. U. S. Geol. Survey No. 410, 1910, p. 64.

[3] Smith, P. S., Geology and mineral resources of the Solomon and Casadepaga quadrangles: Bull. U. S. Geol. Survey No. 433, 1910, pp. 132–133.

The writer [1] has shown elsewhere that the auriferous lode deposits of Seward Peninsula can be classed in two general groups—fissure veins and impregnated zones of fracture. There is also an older series of quartz veins, which lies parallel to the foliation of the schists and has been deformed with them, and these, too, locally carry sulphides and gold.

The distribution of the gold placers in the peninsula has helped to indicate the locus of auriferous mineralization in the bedrock where no other direct evidence was available. This class of evidence goes to show that, in the peninsula as a whole, the limestone-schist contacts were the most favorable places for auriferous mineralization.[2] An example of the relation of the mineralization to the limestone-schist contact is shown in the accompanying sketch map of the Ophir Creek region (fig. 7). The distribution of the placer gold at this locality indicates that it had its source in the limestone-schist contact. Moreover, at several places where this contact was studied in the field evidence of shattering and mineralization was observed. (See section A–B, fig. 7.)

Smith [3] has described the mineral veins of the Solomon-Casadepaga region in considerable detail, and those of the rest of Seward Peninsula are probably similar to these. He shows that there is an older system of quartz veining which may have been formed at a number of different periods of intrusion, all previous to the last epoch of intense deformation. The rock movement deformed the veins, which are now represented by blebs and bunches of quartz, irregularly distributed along the planes of foliation.

Besides being intensely folded and broken, the veins were crushed and then more or less recrystallized. The older veins are most abundant in the schists but occur also in the limestone, where they have usually not been much deformed. Metallic minerals are not common in these deposits, but some of them carry a little gold, some a little sulphide, and some rutile. Most of the younger series of quartz veins, as described by Smith, follow fissures which intersect the lamination of the country rock at different angles. These veins have as a rule suffered little deformation but are locally faulted. Some of them show comb structure and most of them have well-defined walls. These veins are again divisible into two types, one carrying locally visible free gold, with a gangue of quartz and but little sulphide, and the other carrying copper, iron, arsenic, and antimony sulphides, with no visible free gold.

Smith states that quartz veins occur in all the formations mapped, but they seem to be most abundant in the schists and slate. It

[1] Collier, A. J., Hess, F. L., Smith, P. S., and Brooks, A. H., The gold placers of parts of Seward Peninsula: Bull. U. S. Geol. Survey No. 328, 1908, pp. 110–139.

[2] Idem, pp. 121–124. Smith, P. S., Geology and mineral resources of the Solomon and Casadepaga quadrangles: Bull. U. S. Geol. Survey No. 433, 1910, pp. 141–142.

[3] Smith, P. S., Bull. U. S. Geol. Survey No. 433, 1910, pp. 89–93.

appears, from his work as well as that of others, that the limestone-schist contacts afforded conditions favorable to mineralization. The lithology of the country rock, however, except in so far as it affected

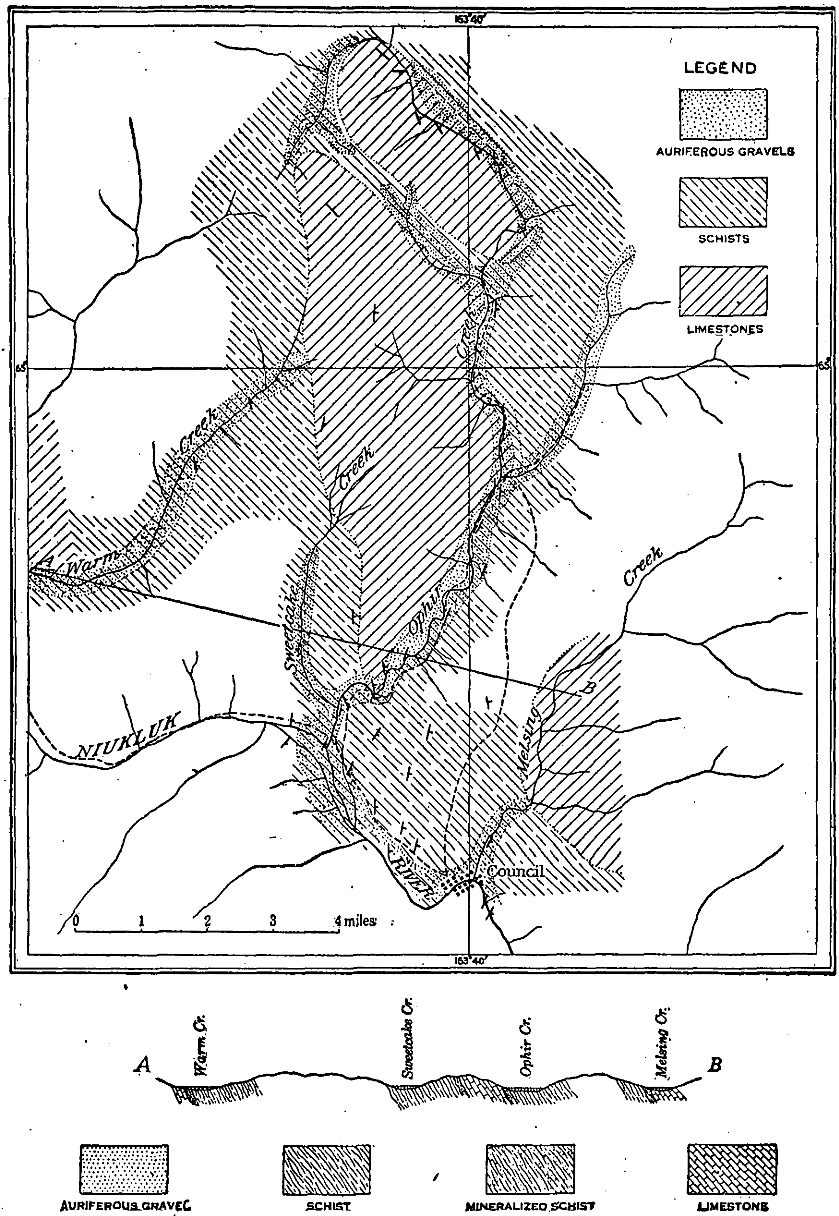


FIGURE 7.—Geologic sketch map and section of Ophir Creek region, Seward Peninsula, showing distribution of gold and of mineralization in relation to the limestone-schist contact.

the character of the fissuring, does not seem to have any influence on the formation of quartz veins. In the Solomon region the veins occurring in the Hurrah slate appear to be most persistent. This rock is well jointed and in places the deposits occur as a stockwork of veins, thus forming a transition to the impregnated zone and fracture type of deposit.

The Big Hurrah mine, in the Solomon basin, is the only auriferous-quartz deposit which has been developed to a productive basis. The country rock is a hard black graphitic quartzite[1] (Hurrah slate), which is much fractured and breaks into rectangular blocks. Numerous fractures occur throughout this formation and in many places it is seamed with quartz veins and stringers. These quartz veins, although they are believed to belong to the youngest system of veining, are more or less deformed. The gold of the Big Hurrah lode is almost entirely free and little or no sulphide is present. Much of the ore is banded with flakes and layers of graphite and graphitic schist. The vein has been opened to a depth of about 250 feet without any noteworthy changes in the character of the ore.

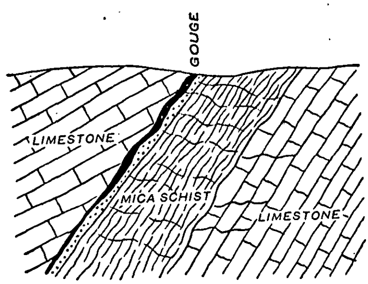


FIGURE 8.—Diagrammatic section of mineralized schist near Bluff, Seward Peninsula. By Alfred H. Brooks, 1905.

Smith also describes some calcite veins occurring in or close to limestone bedrock in the Solomon region. These veins, he states, carry no metallic minerals. It should be noted, however, that near Nome free gold has been found in calcite veins.

The more disseminated types of auriferous deposits of the peninsula, here called mineralized zones of fracture, are probably more common than fissure veins. In general they represent zones of fractured bedrock which have been permeated with mineral-bearing solutions. Some of these contain veins which may be stockwork or stringer-lead deposits. In others there is but little quartz and the deposit is defined by a zone of the bedrock which is heavily pyritized and in some places auriferous. Very few of these deposits are sufficiently well exposed to permit exhaustive study. It is not definitely known whether these deposits represent the older or the younger system of veining, but they probably belong to the younger. Mineralization of this type seems to be most pronounced at the limestone-schist contacts, where its distribution was determined by the fractures resulting from movements along the contact planes between the two formations.

Smith[2] has described the mineralized zones in the schist-limestone contacts of the Solomon and Casadepaga region as consisting of replacements of limestone by quartz with more or less sulphide minerals, of which chalcopyrite is most common. The writer's own

[1] Smith, P. S., Geology and mineral resources of the Solomon and Casadepaga quadrangles: Bull. U. S. Geol. Survey No. 433, 1910, pp. 144-145. Collier, A. J., and others, Gold placers of parts of Seward Peninsula: Bull. U. S. Geol. Survey No. 328, 1908, pp. 228-231.

[2] Smith, P. S., op. cit., pp. 141-142.

observations go to show that at some localities the zone of mineralization may be confined entirely to the schist but close to the limestone contact. An example of this is shown in figure 8, which is a diagrammatic section of a natural exposure near Bluff. Here a mass of schist, which is probably an altered igneous rock, is included between limestone walls. A series of gash veins cut across the foliation of the schist. These veins also penetrate the footwall of limestone. The metalliferous minerals noted in this deposit are pyrite, arsenopyrite, and chalcopyrite and are said to carry some gold.

COPPER.

OUTLINE OF CLASSIFICATION.

Practically all the Alaskan copper deposits thus far developed fall into five general groups determined by mode of origin or mode of occurrence. These are (1) deposits in zones of igneous metamorphism and chiefly near the contact of limestones with granodiorites and diorite intrusive rocks; (2) deposits associated with intrusive rocks, but not within the zone of igneous metamorphism; (3) deposits disseminated in intrusives; (4) deposits associated with ancient volcanic rocks and sediments; and (5) copper-bearing amygdaloids. Each of these groups admits of further subdivisions, which will be discussed later. This classification is summarized below.

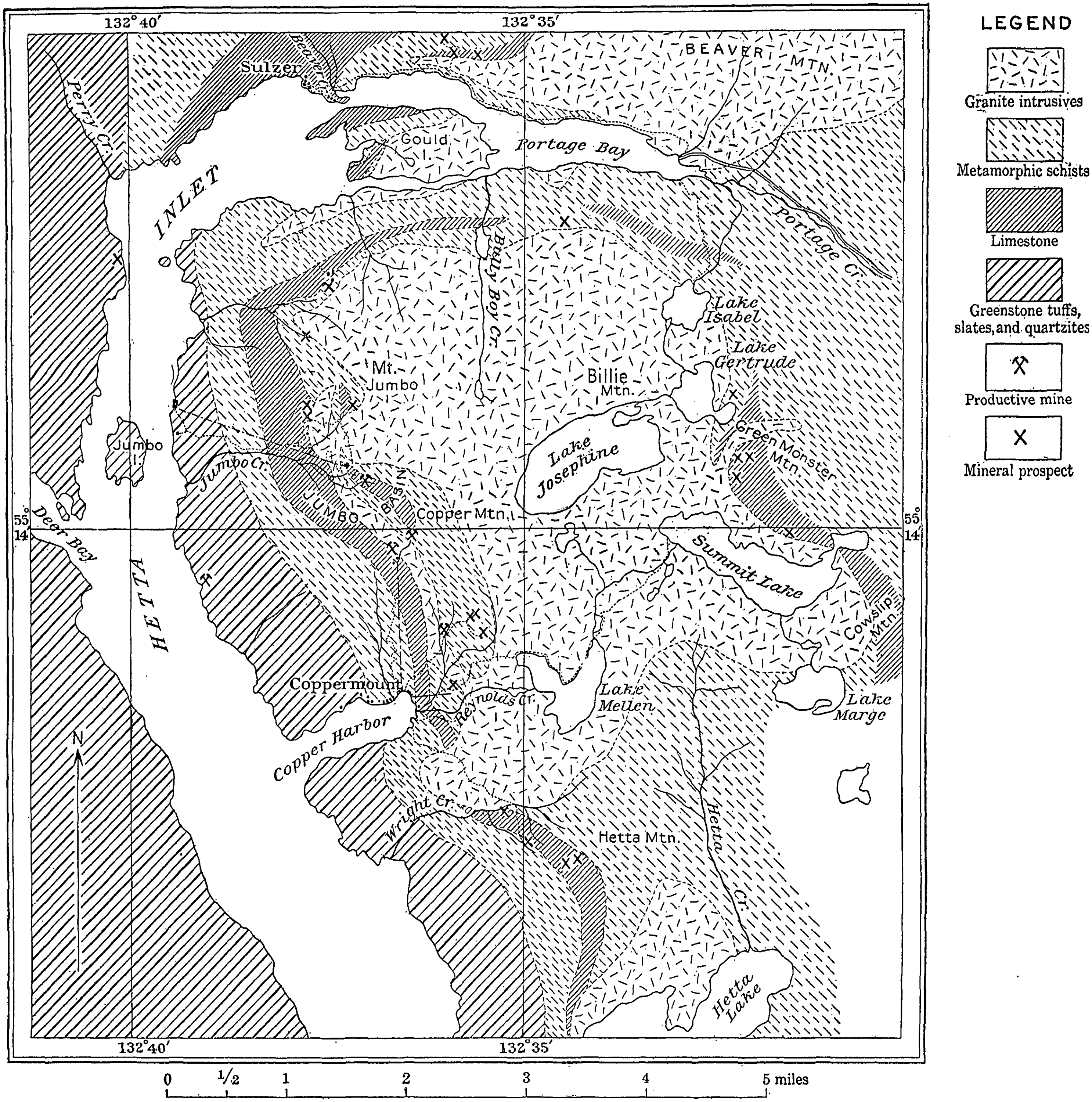
Classification of Alaska copper deposits.

1. Deposits in zones of igneous metamorphism.
    (a) Contact-metamorphic deposits of limestones and intrusive rocks.
    (b) Contact-metamorphic deposits of clastic and intrusive rocks.
2. Deposits associated with intrusive rocks, but not in zones of igneous metamorphism.
3. Deposits disseminated in intrusive rocks.
4. Deposits associated with ancient volcanic rocks and sediments.
    (a) Deposits occurring in greenstones and argillites.
    (b) Deposits occurring in greenstones and limestones.
5. Copper-bearing amygdaloids.

DEPOSITS IN ZONES OF IGNEOUS METAMORPHISM.

Copper-bearing lodes occurring in the contact zones of limestones and intrusive rocks are among the most widely distributed types of deposit in Alaska. The intrusive rocks are probably of Mesozoic age. Such ore bodies are especially abundant on parts of Prince of Wales Island, in the Ketchikan district of southeastern Alaska.[1] The geologic features of some of the best known of these deposits are shown on the accompanying map of the Copper Mountain region (Pl. V). Here an irregular stock of granite is surrounded by limestones and

[1] Wright, C. W., Mining in southeastern Alaska: Bull. U. S. Geol. Survey No. 379, 1910, pp. 80-82.



GEOLOGIC MAP OF COPPER MOUNTAIN REGION, SOUTHEASTERN ALASKA.

Showing relation of copper deposits to intrusive rocks. By C. W. Wright, 1908.

metamorphic schists and the copper deposits occur in the contact zone of limestone or schist adjacent to the granite. The ore bodies occur only where igneous metamorphism has taken place in the sediment adjacent to the granite, and this is by no means the case along the entire contact. Where this alteration has occurred a greenish or reddish rock has been formed composed chiefly of garnet and epidote and almost always carrying some disseminated chalcopyrite, pyrrhotite, and magnetite. This contact zone varies from 25 to 250 feet in width.

The ore bodies, which are of irregular outline and distribution, consist of chalcopyrite and pyrite in a gangue of garnet, epidote, calcite, and some quartz. They carry both gold and silver. Some of the deposits contain much magnetite; others lack this mineral but carry pyrrhotite. According to Wright the lodes were formed from solutions which penetrated along the contact, along preexisting fissures, or along solution channels in the limestone, or are replacement deposits of limestone where no notable opening previously existed. The important ore bodies usually lie along the contact, but from these smaller bodies of vein material branch out, penetrating both walls locally to a distance of a thousand feet.[1] The deposits in the schist near the contact are usually less concentrated than those in the limestone and are usually disseminated[2] along the planes of foliation. As a rule they do not form commercial ore bodies.

Many of the copper deposits of the east side of Prince of Wales Island, including those of Kasaan Peninsula, in the Karta Bay region, are also of the contact type. Wright's investigations[3] show that the sediments of this field include a series of conglomerates and graywackes and tuffaceous schists, which occur in broad areas, and narrow belts of limestones. The whole series has been folded and then extensively intruded by granular rocks which include granites, granodiorites, diorites, and syenites. These intrusives, which occur as irregular stocks and dikes, were followed by an injection of pegmatite dikes and, still later, by a widespread intrusion of porphyry dikes.

Contact deposits similar to those of Copper Mountain form the most widely distributed ore bodies of this region. They occur chiefly in the zone of igneous metamorphism at the contact of limestone and intrusive rocks. A few have been found at the contact of the graywacke-tuff series and the intrusives. The ores of the limestone contact are chalcopyrite, pyrite, pyrrhotite, and magnetite, with a gangue of epidote, garnet, amphibole, calcite, and orthoclase. These

[1] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: Bull. U. S. Geol. Survey No. 347, 1908, pp. 95-96.

[2] Brooks, A. H., and others, Mineral resources of Alaska—Report on progress of investigations in 1908: Bull. U. S. Geol. Survey No. 379, 1909, p. 81.

[3] Wright, C. W., Mining in southeastern Alaska: Bull. U. S. Geol. Survey No. 379, 1909, pp. 76-79.

deposits are typically irregular masses varying from 10 to 250 feet in width.

The shape of one of these ore bodies and its relation to the intrusive rocks is shown by the accompanying plan and section (fig. 9) of the workings of the Mount Andrew mine, on the southwest side of the Kasaan Peninsula. The ore bodies occur at the contact of a large intrusive mass and a belt of crystalline limestone.[1] In the plan and

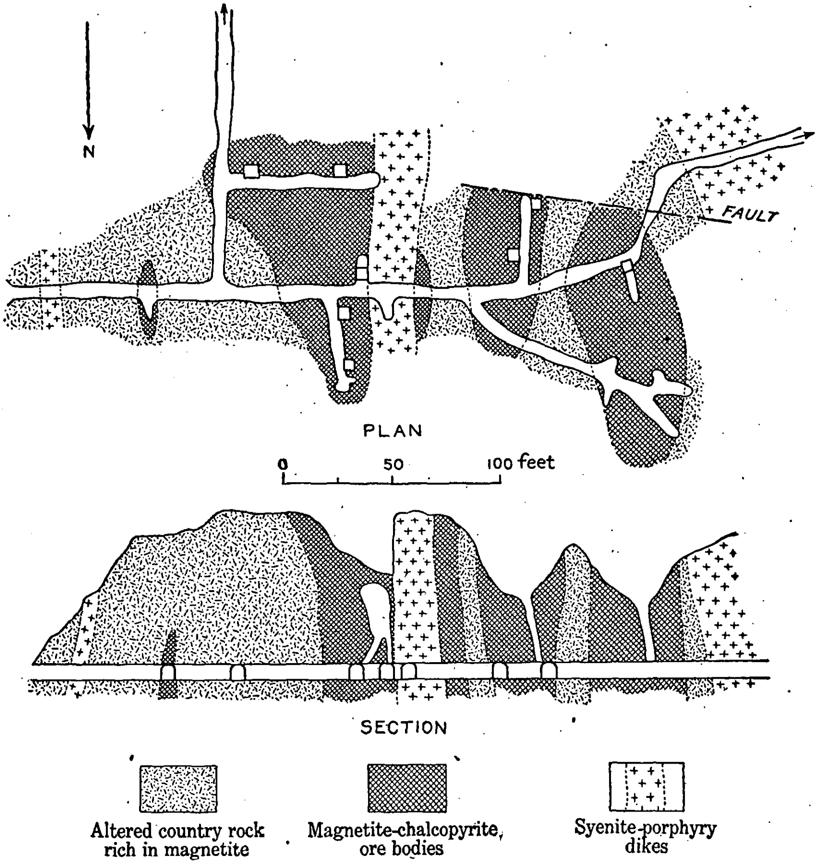


FIGURE 9.—Plan and cross section of Mount Andrew mine workings, Ketchikan district, showing position of ore bodies. By C. W. Wright, 1905.

section the altered country rock represents a metamorphic phase of the limestone and is made up of garnet, epidote, and calcite, together with a large amount of magnetite. This country rock has been cut by dikes of syenite, which are probably apophyses from the main mass of intrusive rocks that lies adjacent to the ore body on the east. The ore is composed essentially of chalcopyrite and magnetite and carries some gold and silver.

[1] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts: Bull. U. S. Geol. Survey No. 347, 1908, pp. 115–117.

In this same region there are copper-bearing lodes which occur in the form of lenses in shear zones in the graywacke and tuffaceous

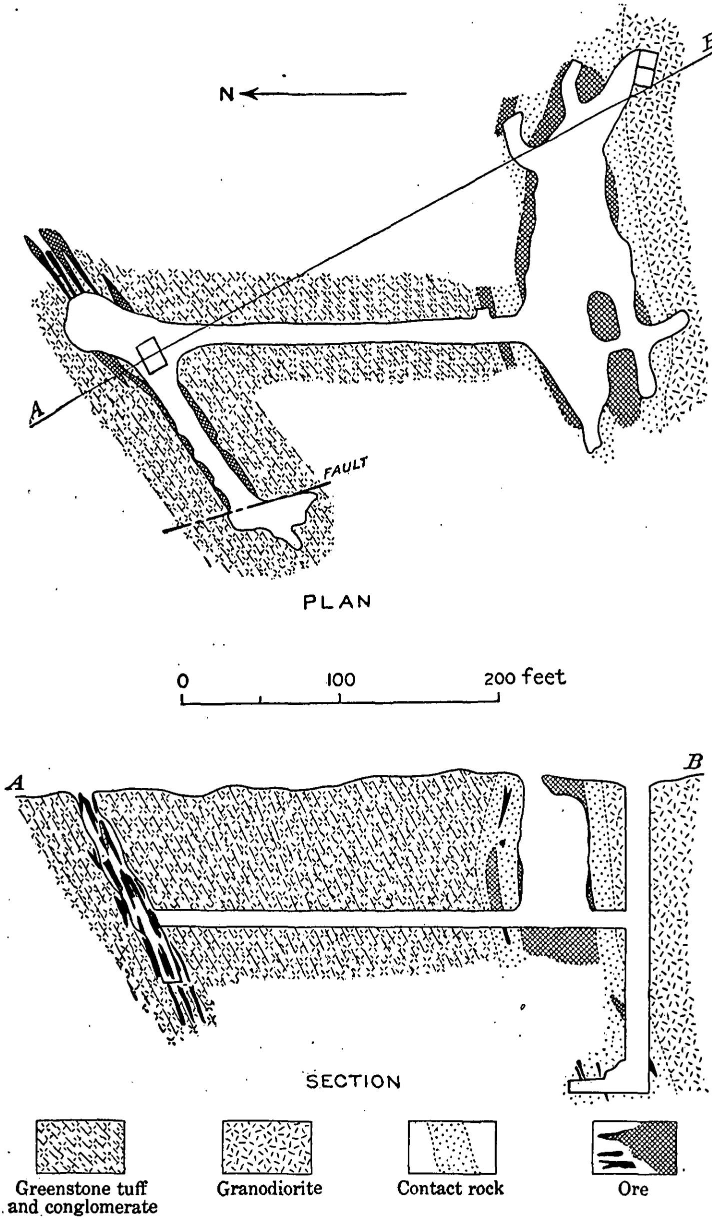


FIGURE 10.—Sketch plan and section of workings at Rush & Brown mine, near Karta Bay, showing ore bodies and relation of mineralization to contact between granodiorite and tuff and conglomerate. By C. W. Wright, 1905.

schist series but apparently in the zone of igneous metamorphism of intrusive masses. Their metallic minerals are chalcopyrite, pyrite, and usually sphalerite, with a quartz and calcite gangue. The Rush &

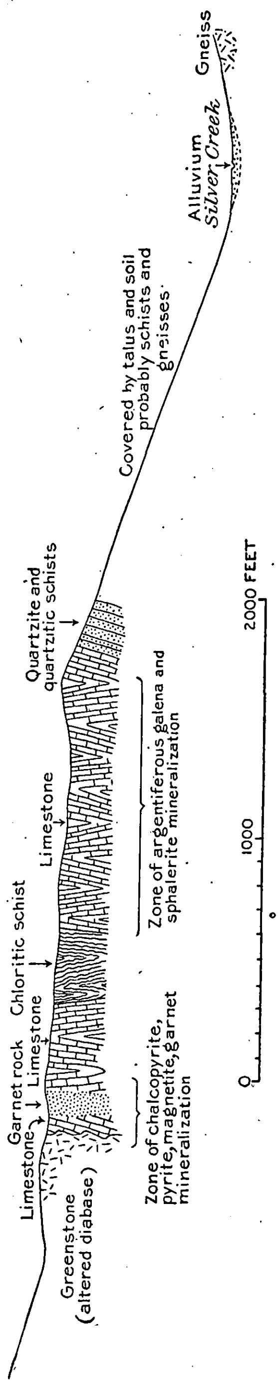


FIGURE 11.—Diagrammatic section near Cottonwood Bay, Iliamna region, showing mineralization at contact zone of limestone and diabase. By G. C. Martin and F. J. Katz, 1909.

Brown mine,[1] near Karta Bay, affords examples of both the contact-metamorphic ore bodies and those occurring in shear zones. Figure 10 indicates the geologic relations of the ore bodies at this locality. These deposits furnish the only example thus far developed in this district of igneous contact deposits in sediments other than limestones.

Moffit and Knopf[2] have described contact-metamorphic deposits of copper which occur in the basin of upper Nabesna River, tributary to the Tanana. These deposits are found in a crystalline limestone at or near the contact with dioritic intrusive rocks. The ores are bornite and chalcopyrite, associated with garnet, epidote, coarsely crystalline calcite, hematite, and scattered flakes of molybdenite. Some of these deposits also contain magnetite. The data at hand, which are fragmentary, as but little development work has been done, indicate that these deposits are similar in character to the contact deposits of southeastern Alaska.

The copper ores west of Cook Inlet, between Iliamna Bay and Iliamna Lake, occur in a contact zone[3] between limestone and a greenstone which is an altered diabase or diorite. The field relations are shown in figure 11. The mineralized zone, averaging 200 feet in width but in places reaching 300 feet, lies chiefly in the limestone but also in the greenstone. It contains chalcopyrite, pyrite, and magnetite, with a gangue of garnet, calcite, quartz, amphibole, and other minerals. The ore bodies consist of those parts of this mineralized zone which carry copper values with some gold.

[1] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts: Bull. U. S. Geol. Survey No. 347, 1908, pp. 123–125.

[2] Moffit, F. H., and Knopf, Adolph, Mineral resources of the Nabesna-White River district, Alaska: Bull. U. S. Geol. Survey No. 417, 1910, pp. 52–55.

[3] Martin, G. C., and Katz, F. J., The Iliamna and Clark lakes region: Bull. U. S. Geol. Survey No. 442, 1910, pp. 194–196.

These Iliamna deposits, so far as the meager information about them permits comparison, bear a close analogy to the better-developed lodes of Prince of Wales Island. While the intrusive is of a more basic character and more highly altered, the contact zone and the ores are very similar. It should be noted that the mineralized zone and the two wall rocks lie within a great stock of intrusive granite, probably of Mesozoic age.

DEPOSITS ASSOCIATED WITH INTRUSIVE ROCKS BUT NOT IN THE ZONE OF IGNEOUS METAMORPHISM.

Some of the copper deposits of the Ketchikan district in southeastern Alaska lie within the zone affected by intrusive rocks but not within the areas of igneous metamorphism.[1] These deposits occur in association with greenstone schists, chloritic schists, and sericite schists, and with argillites and other sedimentary rocks. The greenstone and chloritic schists are probably chiefly altered igneous rocks. Some of them are known to be sheared intrusives. In most localities where the deposits occur intrusive rocks are known to be near at hand, and these are believed to be of Mesozoic age.

These copper-bearing lodes, so far as determined, occur along zones of fracture and usually have lenticular form. In some localities the ores appear to have been deposited in open spaces; in others the ore bodies consist of masses of country rock which have been impregnated by the mineral-bearing solution. No evidence has been seen of replacement of the country rock such as has been noted by Grant and Higgins in the deposits on Prince William Sound. (See p. 81.) The mineralized zone may include one or more ore shoots in the form of bands, veins, or lenses, and these are usually separated from both walls by the impregnated rock carrying lesser values. These deposits are valuable chiefly for their chalcopyrite. They also carry pyrite, pyrrhotite, in some places magnetite, and a little hematite and galena, with a gangue of quartz and calcite, as well as the minerals of the country rock. Among the localities where such deposits are found are Skowl Arm and Niblack Anchorage, both on the east side of Prince of Wales Island. The deposits at the south end of Gravina Island are probably of the same general type.

Ore bodies also occur in the greenstone schists and quartzites which overlie the limestones of Copper Mountain (see Pl. V), a mile or two from intrusive granite. These include both fissure-vein and shear-zone deposits. The ores contain pyrite and chalcopyrite, with a small amount of sphalerite.

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[1] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: Bull. U. S. Geol. Survey No. 347, 1908, pp. 128-140. Brooks, A. H., Preliminary report on the Ketchikan mining district: Prof. Paper U. S. Geol. Survey No. 1, 1902, pp. 74-96.

In this group should also be included copper-bearing fissure veins occurring in limestone of the Kasaan Peninsula region.[1] These veins carry chalcopyrite, galena, sphalerite, and tetrahedrite, with quartz, calcite, and barite as gangue minerals. In some places these deposits lie along the margins of intrusive dikes.

DEPOSITS DISSEMINATED IN INTRUSIVE ROCKS.

Copper ores occur as disseminated deposits in the intrusive rocks of the Kasaan Peninsula region.[1] The only commercial ore body of this type which has been developed is that of the Goodro mine, near the upper end of Kasaan Bay. This occurrence has been recently described by Knopf[2] as "a heavy green dioritic rock containing much biotite and, as the main copper-bearing mineral, scattered particles of bornite, with which are associated sporadic blebs of chalcocite and chalcopyrite." The ore body has been opened to a depth of 94 feet, where the copper content is said to be 2 per cent higher than at the surface. Knopf points out that this may be due to the greater prevalence of chalcocite on the lower level.

DEPOSITS ASSOCIATED WITH ANCIENT VOLCANIC ROCKS AND SEDIMENTS.

The fourth group of copper deposits comprises those which are associated with greenstones (altered volcanic rocks) and sediments of various types. These deposits, so far as known, have no direct relation to igneous intrusive rocks, but it is possible that in the deposits of the Prince William Sound type belonging to this group there may be a connection between the genesis of the ores and certain basic intrusive rocks. Of a different type, though belonging to this same general group, are deposits of the Chitina region which occur chiefly in limestones and are not connected with any intrusive rocks. While definite proof is lacking, it seems probable that the copper of both the Prince William Sound and the Chitina deposits was derived from copper minerals disseminated in the associated ancient volcanic rocks.

COPPER-BEARING LODES IN GREENSTONES AND ARGILLITES.

The best-known examples of the deposits in greenstones and argillites are those occurring in the Orca group of Prince William Sound and adjacent regions. The following description is abstracted from a report by Grant and Higgins.[3] The copper-bearing lodes occur along zones of fracture, in most of which shearing has taken

[1] Wright, C. W., Mining in southeastern Alaska: Bull. U. S. Geol. Survey No. 379, 1909, p. 78.
[2] Knopf, Adolph, Mining in southeastern Alaska: Bull. U. S. Geol. Survey No. 442, 1910, p. 141.
[3] Grant, U. S., and Higgins, D. F., Reconnaissance of the geology and mineral resources of Prince William Sound, Alaska: Bull. U. S. Geol. Survey No. 443, 1910, pp. 53-71.

place. These zones are mainly in greenstones that are altered basic lava flows and tuffs, with some intrusive rocks. Some of the mineralized shear zones occur in slates and graywackes and some along the contacts of the sediments and the greenstones. The shear zones strike parallel to the major structures of the region, with usually a steep dip. In some places the deformations have resulted in fracturing rather than shearing. So far as can be determined from the evidence in hand, the movements did not, as a rule, produce any notable open spaces, but there are exceptions to this, for at some localities fissure veins have been observed. Mineral deposition in the shear zones in part followed the open spaces thus formed and in part impregnated the country rock or replaced it where no notable open spacing occurred. Development has not proceeded far enough to admit of precise statement as to the shape of the ore bodies, but some of them at least appear to have a lenticular form, outlined by planes of movement. Some of the ore bodies have no well-defined walls. In many of the deposits there is an ore shoot, made up of more or less solid layers of metallic sulphide within the mineralized zone. These ore shoots vary more in dimensions from place to place than the deposits as a whole. Chalcopyrite is the most abundant of the metallic minerals and is usually associated with pyrrhotite. The proportion of these minerals varies greatly in a single ore body. Pyrite also occurs but is much less abundant. Among the rarer metallic minerals are galena, bornite, sphalerite, and magnetite. The chief gangue minerals are quartz, calcite, epidote, and chlorite. The ores that have been shipped from this district carried considerable silver but only a small amount of gold.

The best-developed ore bodies of the district are those of the Ellamar and Beatson-Bonanza[1] mines. At the Ellamar the lode consists of a lens-shaped ore body, whose greatest horizontal dimension is 190 by 80 feet, occurring in a slate-graywacke series. The mine workings extend to a depth of 600 feet. The ore body consists of chalcopyrite, pyrite, and pyrrhotite, with some included masses of country rock. At the Beatson-Bonanza the ore occurs in a zone of hard greenish flinty rock which, for want of a better name, can be designated a hornfels, though its sedimentary origin has not been proved. This hornfels, which forms the country rock at the mine, occurs in a belt of slates and graywackes. The ore, which is chiefly chalcopyrite, occurs in fractures and as replacements in the hornfels. It is found disseminated in the hornfels and also as bands of nearly pure sulphides (chalcopyrite, pyrite, and pyrrhotite), which are in general parallel to the bedding of the slates and graywackes. Some

[1] Formerly called the Bonanza, but not to be confused with the mine of that name in the Chitina region.

faulting has taken place since the ore was deposited. Some basic dikes are present.

Among the deposits differing from those described above may be mentioned one occurring on Knight Island and near Mummy Bay, in which a coarse-grained diabase has been heavily charged with pyrrhotite and chalcopyrite. Another type, which is found on Orca Bay, is made up of epidotized stringers which occur in a crushed amygdaloidal basalt. These stringers carry native copper, chalcopyrite, bornite, and chalcocite in a gangue of quartz and epidote. In a few localities there are some well-defined fissure veins filled with quartz, pyrrhotite, pyrite, and chalcopyrite.

While these deposits have not been traced to the mineralizing influence of igneous rocks, yet Grant and Higgins have pointed out that certain basic intrusives are later than the shear zones and that the ores may bear a genetic relation to these rocks. Copper-bearing lodes of similar geologic occurrence have been found in the eastern part of Kenai Peninsula.[1]

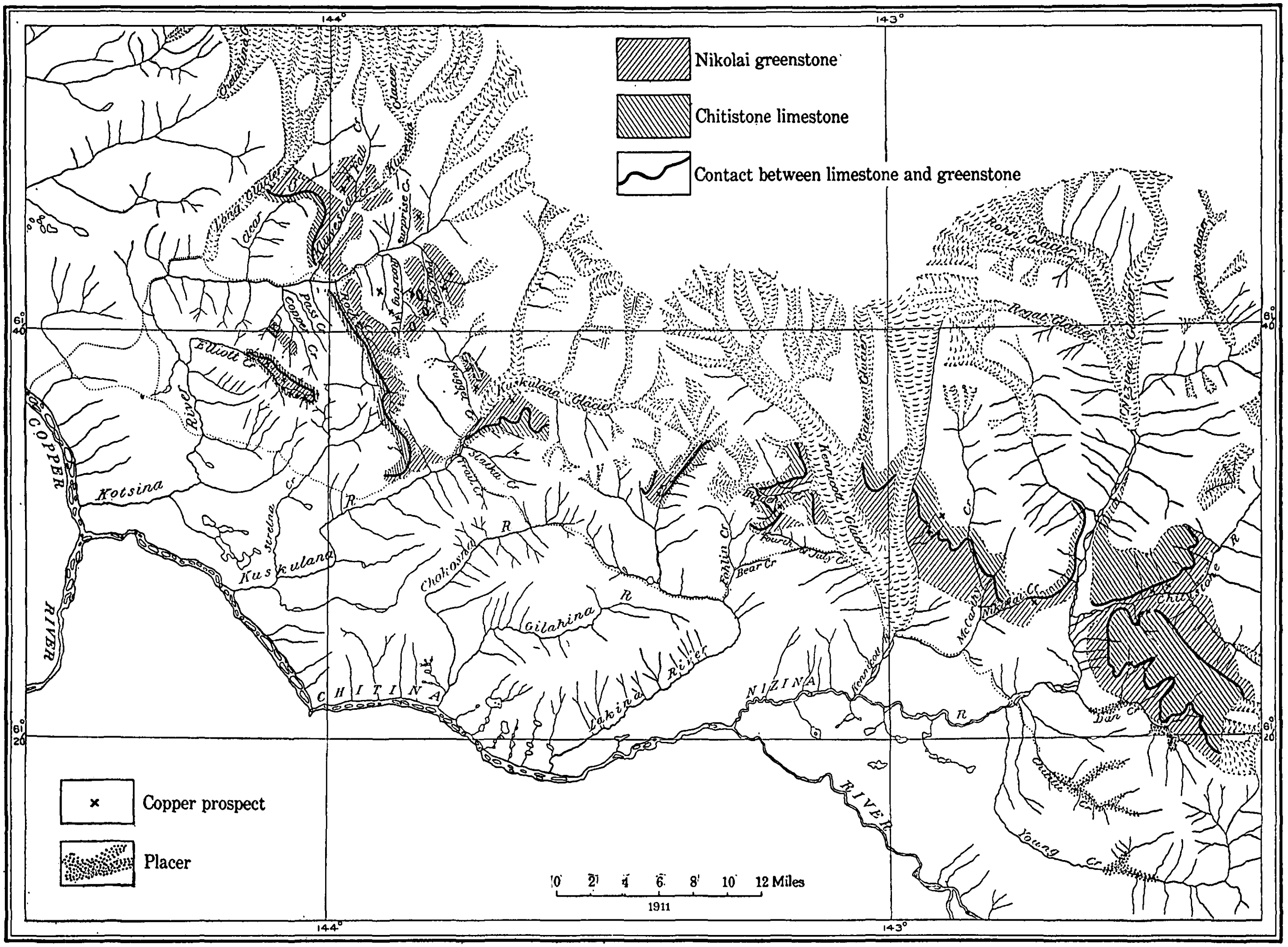
COPPER-BEARING LODES IN ASSOCIATION WITH GREENSTONES AND LIMESTONES.

The copper deposits which stretch along the southern flank of the Wrangell Mountains, in the Kotsina-Chitina district, have been investigated by a number of geologists,[2] but most of the following account is based on the observations and deductions of Moffit. With regard to copper resources, two formations of this field are of first importance. The older comprises a great sequence of ancient basaltic lavas, some of which are amygdaloidal, with which some sedimentary beds are intercalated. This series aggregates at least 3,000 to 4,000 feet in thickness and is called the Nikolai greenstone. This is conformably overlain by the Chitistone limestone, of Triassic age, made up of heavily bedded bluish-gray limestone aggregating 3,000 to 4,000 feet in thickness. The contact between these two formations forms the locus of the most important ore bodies which have yet been developed (see map, Pl. VI), but some copper occurs throughout the greenstone and copper lodes have been found in the limestone a long distance from the contact. The largest ore bodies so far found are those occurring within the limestone and within a thousand feet of the greenstone contact.

The conditions favorable to the deposition of copper appear to have been determined chiefly by the readiness with which the mineral-bearing solutions could circulate. Therefore the openings developed

[1] Grant, U. S., and Higgins, D. F., Preliminary report on the mineral resources of the southern part of Kenai Peninsula: Bull. U. S. Geol. Survey No. 442, 1910, pp. 166–178.

[2] Schrader, F. C., and Spencer, A. C., Geology and mineral resources of a portion of the Copper River district, Alaska, a special publication of the U. S. Geol. Survey, 1907. Moffit, F. H., and Maddren, A. G., Mineral resources of the Kotsina-Chitina region, Alaska: Bull. U. S. Geol. Survey No. 374, 1909. Moffit, F. H., and Capps, S. R., Geology and mineral resources of the Nizina district, Alaska: Bull. U. S. Geol. Survey No. 448, 1911.



GEOLOGIC SKETCH MAP OF KOTSINA-CHITINA COPPER BELT.

By F. H. Moffit, 1907.

by faulting, jointing, and shearing, which gave opportunity for this circulation, constituted one of the prime requisites to the formation of ore bodies. The most promising deposits have been found along lines of movement which intersected the contact at different angles. It also appears that the plane of the contact between the two formations locally furnished passages for the solutions, even where no movement had taken place.

A few deposits which can be classed as fissure veins have been found, but most of them are more or less irregularly distributed and represent replacements of the country rock by materials brought in solution along openings, many of which were very minute, caused by deformation.

Most of the sulphide copper deposits within the greenstone thus far prospected consist of irregular masses and blebs of the ore, distributed along zones of fracture, and in many places do not appear to have well-defined walls. Bornite and chalcopyrite are the most common of the copper ores in the greenstone, but some promising chalcocite ore bodies have been found. The copper deposits within the greenstones usually include very little gangue. Some vein deposits have also been found in the greenstone, and their ores are also chiefly bornite and chalcopyrite with a gangue consisting mainly of calcite, with some quartz and usually epidote.

Moffit regards the native copper deposits that have been found in the greenstone of the Kotsina-Chitina belt as probably secondary and due to the reduction of sulphides or oxides. The most common types of these deposits are those in which grains and irregular and tabular masses of native copper are distributed through certain zones in the greenstones. These are most common in the amygdaloidal phases of the greenstone, and here many of the amgydules are filled with native copper. At several localities carbonaceous matter and copper oxide occur with these native copper deposits. Some of the alluvium carries a large amount of placer copper which appears to have been derived from deposits of this type. Much of this placer copper is in thin sheets as if derived from planes of jointing or foliation. Nuggets of placer copper weighing several hundred pounds are not uncommon, and one mass of native copper found on Nugget Creek weighed 2 or 3 tons.

The most important feature of the deposits in the limestone are summarized by Moffit and Capps [1] as follows:

> Copper deposits in limestone were formed by replacement of the limestone as a whole by copper minerals in solutions circulating along fracture planes such as faults, shear zones, or joints. The copper minerals are chalcocite and bornite, accompanied by malachite, azurite, and in places covellite as alteration products. As a rule, the

[1] Moffit, F. H., and Capps, S. R., Geology and mineral resources of the Nizina district, Alaska: Bull. U. S. Geol. Survey No. 448, 1911, p. 79.

boundary between ore and country rock is distinct, although the form of the ore body itself may be very irregular. This is particularly true where the copper mineral is chalcocite. In deposits of bornite in limestone a dissemination of the copper mineral through the adjacent country rock was noticed, and in such examples there is a gradation from ore to country rock similar to that in the greenstone deposits. One of the best examples of this kind shows a large proportion of chalcocite associated with the bornite, and the deposition of the copper was accompanied by a thorough silicification of the limestone. Large masses of chalcocite like that of the Bonanza property are distinctly replacement deposits in fracture zones. No fragments of limestone are included in the body of the ore, although isolated masses of chalcocite are scattered through the limestone. The ores are most frequent near the limestone-greenstone contact, yet some of them must be fully 1,000 feet above the base of the limestone. It is a notable fact that azurite is far more common as a secondary oxidation product in

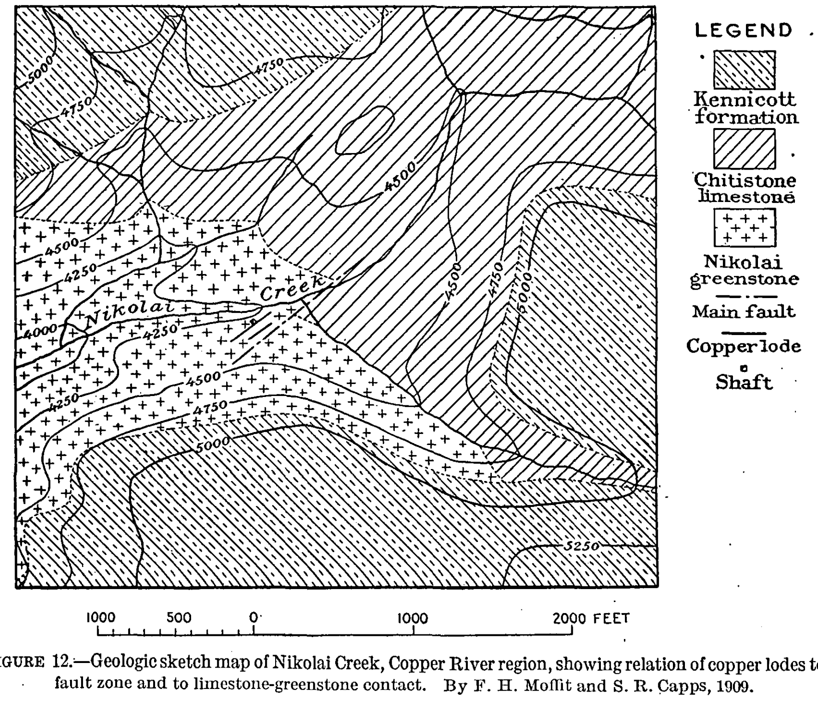


FIGURE 12.—Geologic sketch map of Nikolai Creek, Copper River region, showing relation of copper lodes to fault zone and to limestone-greenstone contact. By F. H. Moffit and S. R. Capps, 1909.

the limestone replacement deposits than malachite and that it is not common in the deposits in greenstone. Small veins of azurite with cores of chalcocite show distinctly that the azurite in the Bonanza mine was produced by the alteration of chalcocite. Covellite originated in a similar manner.

The Nikolai copper property, located on a tributary of McCarty Creek, affords an example of the vein type of deposit in the greenstone. It lies in a fault zone which intersects and offsets the limestone-greenstone contact. (See fig. 12.) The vein has been traced horizontally within about 400 feet of this faulted contact, though its nearest point to the limestone is only about 50 feet distant. According to Moffit the deposit is in part a replacement of the greenstone, in part a filling of a preexisting fissure. Chalcopyrite is the principal copper mineral, but with it is considerable bornite. With these are associated calcite, epidote, and quartz as gangue minerals.

At the Bonanza mine is the largest and best-developed ore body of the district. The mine is located at an altitude of about 6,000 feet,

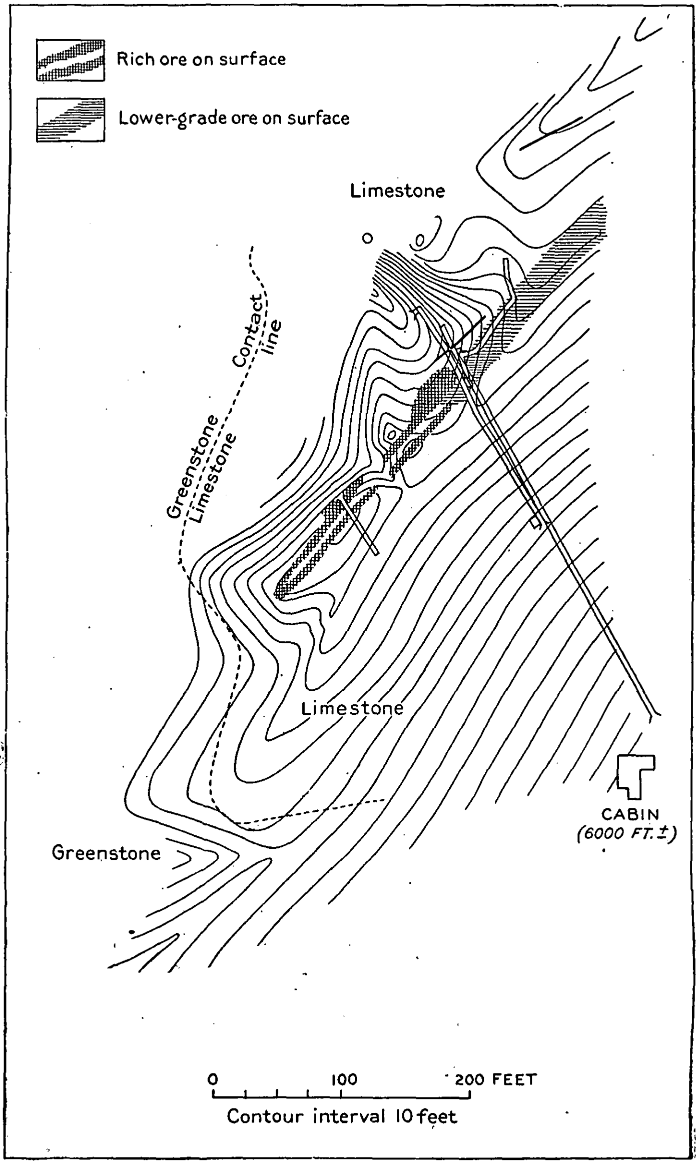


FIGURE 13.—Sketch map of the vicinity of the Bonanza mine, Copper River region, showing relation of copper deposits to limestone-greenstone contact. By F. H. Moffit and S. R. Capps, 1909.

near the crest of the ridge which separates the drainage of upper Kennicott River from McCarty Creek. The deposit includes bodies of chalcocite, which occur in a zone of fracture traversing the limestone and trending northeastward, in which direction it has been traced for about 1½ miles. The limestone-greenstone contact, which is about 40 feet from the nearest point on the ore body, is not offset by the fault but has been subjected to some minor displacements. (See fig. 13.) The zone of fracture has been affected by more than one line of movement. In the sheeted zone formed by this faulting, which is from 50 to 60 feet wide, occur the copper deposits, which range from small, irregularly distributed masses of copper to large, well-defined veins. The deposit appears to end above the limestone-greenstone contact, but a little mineralization is observable in the greenstone.

The ore is chalcocite, and but little else is included in the deposit. Azurite has been formed as an oxidation product, and some covellite is also present.

It is a significant fact that promising deposits of similar character occur on the extension of this zone of fracture on the McCarty Creek side of the divide and have been prospected. There appears, however, to be a barren area along the fracture zone between the Bonanza and the deposits on McCarty Creek, but even here copper-bearing minerals are found in places.

No other copper deposits have been developed in Alaska which are similar in association to those of the Kotsina-Chitina region. There are, to be sure, copper lodes in limestone and in greenstone in different parts of the Territory, but in none of these are the conditions of occurrence exactly similar to these described above. Some of the copper deposits of the White and Nabesna River regions occur in limestone, but these are for the most part in the contact zones of intrusive rocks [1] and have already been described. There are also some deposits in the ancient volcanic rocks of this northern field which may prove to be similar to those in the greenstone of the Chitina Valley. On the whole, however, the deposits of the two copper belts on the north and south sides of the Wrangell Mountains appear to be dissimilar in occurrence and genesis.

COPPER-BEARING AMYGDALOIDS.

Primary native copper has been found by Moffit and Knopf [2] in the upper White River basin and constitutes the only occurrence of this kind known in Alaska. The property containing this deposit, called the Copper King claim, is located at the head of the Middle Fork of White River. The country rock is a series of basaltic flows, breccias, and tuffs of Carboniferous age. To quote from Moffit and Knopf's report:

> Native copper is apparently limited in its occurrence to a certain definite volcanic sheet—a reddish lava that is locally amygdaloidal to a high degree. For 200 feet

[1] Moffit, F. H., and Knopf, Adolph, Mineral resources of the Nabesna-White River district, Alaska: Bull. U. S. Geol. Survey No. 417, 1910, p. 54.

[2] Idem, pp. 55–56.

along the outcrop of this sheet metallic copper intergrown with prehnite, calcite, and zeolites can be found here and there in encouraging amounts. The cupriferous portion of the amygdaloid appears to be about 6 feet thick, but as almost no development work has been done on the property [1908], figures of this kind have little value. The copper occurs as irregular reticulating masses of metal several inches long and as small lumps and minute particles embedded in the minerals that fill or line the former vesicles in the lava flow. In places these minerals either ramify in small veinlets through the body of the rock surrounding the amygdules or form irregular masses, and such places are eminently favorable for metallic copper.

These deposits are considered primary in the sense that the copper was deposited in the amygdaloidal or native state and is not the result of oxidation of sulphides, as is believed to be the case in the copper-bearing amygdaloid of the Nikolai greenstone.

SILVER, LEAD, AND ZINC.

Practically all the gold deposits and many of the copper deposits carry more or less silver. Galena, as has been shown, is not uncommon as an accessory mineral in these deposits. There are also some lodes in Alaska which are regarded as valuable because of their silver and lead contents. These nearly always carry also some subordinate gold values. Argentiferous galena-bearing fissure veins [1] have been developed on the south arm of Cholmondeley Sound—an indentation on the east side of Prince of Wales Island, in the Ketchikan district. These veins cut across both schists and limestone. According to the Wrights, where they crosscut the limestones they are replacement deposits. These veins carry galena, with a small amount of chalcopyrite and sphalerite, in a gangue of quartz, siderite, and calcite. Another group of galena deposits occurs about 12 miles east of Wrangell, in southeastern Alaska.[2] Here there is a slate-schist belt about a mile wide lying between granite areas. These altered sediments are traversed by acidic porphyry and aplite dikes, and in these or along the contacts the galena deposits occur. The deposits are fissure veins, which appear to be persistent. They are heavily mineralized with galena, sphalerite, pyrite, and chalcopyrite.

Some galena deposits [3] have also been opened on Coronation Island, which lies near the entrance to Chatham Strait, in southeastern Alaska. The bedrock of the island, so far as known, consists of Paleozoic limestones and schists, which have been intruded by granite. The ore deposits are irregular masses within a limestone country rock. Besides the galena, tetrahedrite and sphalerite are present in the ores.

Among the many localities where galena ore deposits have been found in Alaska, that in the Fish River basin, in the eastern part

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[1] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: Bull. U. S. Geol. Survey No. 347, 1908, pp. 187–188.

[2] Idem, pp. 188–190.

[3] Idem, pp. 190–191.

of Seward Peninsula, deserves mention. One of the first attempts at lode mining in Alaska was at this locality, at the Omilak mine, in 1882. According to Smith and Eakin,[1] the country rock consists of crystalline limestone and schists and also some more or less schistose igneous rocks which are classed as greenstones. The galena ores occur in a zone of fracture in the limestones, near the contact with some of the schistose greenstones. Within this zone they are irregularly distributed in masses and blebs. The galena carries gold and a large amount of silver.

Some galena deposits have also been found in the western part of Seward Peninsula, in the Lost River and Brooks Mountain regions.[2] These occur in shattered zones which traverse limestones of early Paleozoic age. Some of them are clearly contact-metamorphic deposits of granite and limestone; others are more or less intimately associated with quartz porphyry dikes.

No deposits valuable for their zinc contents have been found in Alaska. As has been noted in the preceding pages, sphalerite is a common accessory mineral in the gold, silver, and some of the copper deposits.

TIN AND TUNGSTEN.

Cassiterite in the form of stream tin is not an uncommon mineral in the auriferous gravels of the Yukon-Tanana region and Seward Peninsula, but its only known occurrences of possible commercial value are limited to the York region, in the western part of Seward Peninsula. Stream tin, however, forms a considerable percentage of the concentrates from the sluicing operations on some of the placer mines on tributaries of Patterson Creek, in the Hot Springs district, of the Tanana Valley. Considerable stream tin, associated with wolframite, has also been found on Deadwood Creek,[3] in the Birch Creek district. Scheelite, another tungsten mineral, has been found both in some of the auriferous gravels and in some small quartz veins on Seward Peninsula.

The only lode-tin deposits of which there is definite knowledge are those found in the western part of Seward Peninsula. Contributions to the knowledge of these lode and placer tin deposits have been made by several geologists,[4] but the following statements are

[1] Smith, P. S., and Eakin, H. M., A geologic reconnaissance in southeastern Seward Peninsula and the Norton Bay-Nulato region: Bull. U. S. Geol. Survey No. 449, 1911, pp. 130–133.

[2] Knopf, Adolph, The mineral deposits of the Lost River and Brooks Mountain regions of Seward Peninsula: Bull. U. S. Geol. Survey No. 345, 1908, pp. 268–271.

[3] Johnson, B. L., Occurrence of wolframite and cassiterite in the gold placers of Deadwood Creek, Birch Creek district: Bull. U. S. Geol. Survey No. 442, 1910, pp. 246–250.

[4] Brooks, A. H., A new occurrence of cassiterite in Alaska: Science, new ser., vol. 13, No. 328, p. 593; A reconnaissance of the Cape Nome and adjacent gold fields of the Seward Peninsula, Alaska, 1900, a special publication of the U. S. Geol. Survey, 1901, pp. 132–139. Collier, A. J., A reconnaissance of the northwestern part of Seward Peninsula, Alaska: Prof. Paper U. S. Geol. Survey No. 2, 1902, p. 49; Tin deposits of the York region, Alaska: Bull. U. S. Geol. Survey No. 229, 1904. Hess, F. L., The York tin region: Bull. U. S. Geol. Survey No. 284, 1906, pp. 145–157. Knopf, Adolph, Geology of the Seward Peninsula tin deposits: Bull. U. S. Geol. Survey No. 358 1908.

based almost entirely on the report of Knopf, who has made a more exhaustive study of this field than anyone else.

The York region, as here defined, comprises an area about 50 miles in width, including the west end of Seward Peninsula. A series of more or less altered argillitic slates, which contain much arenaceous material, comprise the oldest rocks of the field. (See

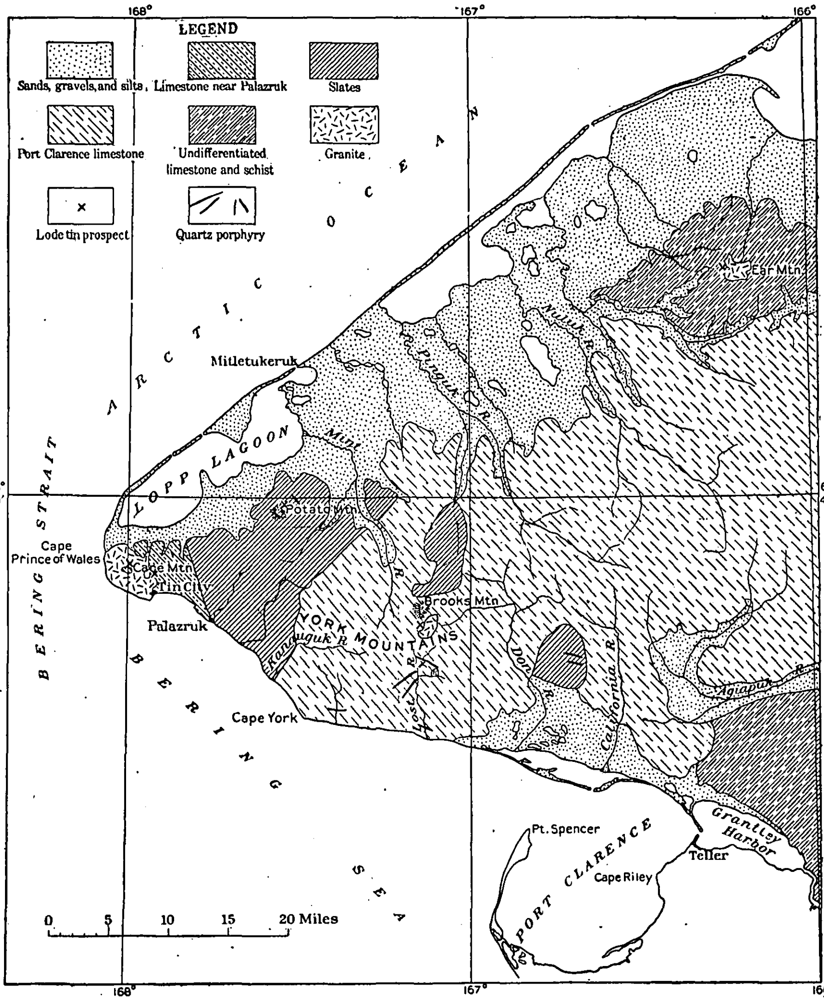

FIGURE 14.—Geologic sketch map of west end of Seward Peninsula, showing relation of tin deposits to intrusive rocks. By Adolph Knopf, 1907.

fig. 14.) These appear to be overlain on the east by heavy unaltered limestones of early Paleozoic age. On the west they are faulted against some crystalline limestones and schists, which are of Carboniferous age. Greenstones occur in the slates, and granites and quartz porphyry dikes cut all the formation. Knopf [1] summarizes

[1] Op. cit., p. 64.

the different types of cassiterite-bearing lodes, which in the slates are genetically related to intrusive granites, as follows:

1. In a tourmaline-axinite hornfels.
2. In beds of actinolite rock which are probably interstratified with slates.
3. In tourmalinized margins of granite masses and granitic dikes.
4. In mineralized quartz porphyry dikes.
5. In quartz veins cutting granite and accompanied by impregnation of the adjoining granite.
6. In quartz stringers cutting slates and limestones.

These deposits carry a large number of mineral species, which it is not worth while to enumerate here. Among the tungsten minerals wolframite and scheelite are worthy of note.

The cassiterite and wolframite of the alluvium in Deadwood Creek have been traced by Johnson[1] to a granite-schist contact zone, and prospectors report a small vein carrying these minerals in the vicinity. Johnson has listed the following minerals as occurring in the concentrates from this alluvium: Wolframite, cassiterite, magnetite, ilmenite, arsenopyrite, pyrite, galena, limonite, garnet, tourmaline, and quartz. The other creeks in the Yukon-Tanana region which have yielded stream tin all lie in areas of granite intrusions.

IRON.

In the absence of any development of the coking coals and the lack of transportation, there has been little encouragement to prospect Alaska's iron ores. Therefore there are few data on which to base conclusions regarding their geologic occurrence. Three types of iron-ore deposits have been recognized—(1) iron ores lying in the zones of igneous metamorphism, due to intrusion and to be classed as contact ores; (2) vein deposits; (3) deposits of magmatic segregations. The occurrence of magnetite in the contact zones of limestones and other sediments and intrusive rocks has already been noted in the description of the copper deposits with which these iron ores are associated (pp. 74–79). The best known of this type of magnetite deposits are those of Prince of Wales Island. Of these occurrences the Wrights[2] say:

> At the copper mines in Kasaan Peninsula magnetite forms about half of the ore mass and occurs in large amounts in some of the deposits in the vicinity of Hetta Inlet. * * * At several places on Prince of Wales Island magnetite occurs in masses sufficiently high in grade to make an iron ore, though no attempt has been made to mine it as such.

No analyses are available of these magnetite ores, but similar types of deposits have been mined on Tuxedo Island, in British Columbia,

[1] Johnson, B. L., Occurrence of wolframite and cassiterite in the gold placers of Deadwood Creek, Birch Creek district: Bull. U. S. Geol. Survey No. 442, 1910, pp. 246–250.

[2] Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: Bull. U. S. Geol. Survey No. 347, 1908, p. 89.

and these have an average of 55 to 60 per cent of metallic iron,[1] while the phosphorus content of most of them is low enough to make them fall within the Bessemer limit. The sulphur content, however, is high. Magnetite occurs in similar geologic association on Prince William Sound, in the Iliamna region, and in the Nabesna region, as well as elsewhere in Alaska.

So far few examples of the vein type of iron deposits have been found. Schrader [2] described a magnetite ore body which appears to be a vein in the Nabesna region. This vein is well defined and occurs at a contact between limestone and diabase. Grant and Higgins report the occurrence of hematite and magnetite bearing veins in the Prince William Sound region.

Iron-ore deposits of the segregated type occur near Haines, in southeastern Alaska, but their commercial value remains to be established. These, according to Knopf,[3] consist of primary magnetite disseminated in a basic rock composed of pyroxene and hornblende. The best specimens seen carried a maximum of 30 per cent of magnetite. A microscopic examination showed the presence of apatite and the analysis of one sample showed 3.91 per cent of TiO_2.

Chromite occurs near Port Chatham, on Kenai Peninsula.[4] The country rock is a peridotite, composed essentially of olivine, which contains small grains of chromite. In places the chromite is abundant and is segregated in small bands, and these form the ore deposits.

ANTIMONY.

Stibnite, the sulphide of antimony, is one of the most widely distributed ores in Alaska. As has been noted, it occurs as an accessory mineral in many of the ore bodies of types already described. It remains to give an account of the occurrence of stibnite-bearing lodes in which the stibnite is the dominating metallic mineral. In all these occurrences the stibnite-bearing lodes carry more or less gold, and a number of them probably carry enough gold to warrant classifying them with the auriferous lodes.

In southeastern Alaska stibnite has been recognized only as an accessory mineral in some of the gold ores. Grant and Higgins [5] have described an occurrence of stibnite on Port Wells, Prince William Sound. At this locality there is a zone of brecciation along a fault

[1] Lindeman, Eimar, Iron-ore deposits of Vancouver and Tuxedo Islands, British Columbia: Pub. No. 47, Canada Dept. Mines, Mines Branch, Ottawa, 1910.

[2] Mendenhall, W. C., and Schrader, F. C., Mineral resources of the Mount Wrangell district, Alaska: Prof. Paper U. S. Geol. Survey No. 15, 1903, pp. 65–66.

[3] Knopf, Adolph, The occurrence of iron ore near Haines: Bull. U. S. Geol. Survey No. 442, 1910, pp. 144–146.

[4] Grant, U. S., and Higgins, D. F., Preliminary report on the mineral resources of Kenai Peninsula: Bull. U. S. Geol. Survey No. 442, 1910, pp. 168–169.

[5] Grant, U. S., and Higgins, D. F., Reconnaissance of the geology and mineral resources of Prince William Sound, Alaska: Bull. U. S. Geol. Survey No. 443, 1910, p. 78.

line which cuts across the country rock of black slate and graywacke. These sediments are cut by acidic dikes in the vicinity. The stibnite ore occurs in a band of vein quartz along the hanging wall of the shear zone. No other minerals were noted in this deposit. Grant and Higgins [1] also report the occurrence, near Kenai Lake, north of Seward, of a fine-grained sheared acidic dike which contained particles and stringers of stibnite. Of the stibnite in the Fairbanks district Prindle [2] says:

> Stibnite was common in the concentrates from the placers in the early days of mining in the Fairbanks district and was afterward found in place in the bedrock at several localities in widely different parts of the district. It occurs in place here and there in the drainage area of Cleary Creek, and, together with arsenopyrite, accompanies the gold in the richest of the quartz veins. It has been found as narrow stringers composed almost entirely of massive stibnite crosscutting quartzite schist or forming a network of stibnite veins between fragments of brecciated schist; in veins of quartz and stibnite, where the massive stibnite occupies the spaces left between quartz crystals; and as fine needle-like crystals or small crystalline groups along with some fresh, clear quartz areas in more or less fractured quartz veins. At one locality stibnite was found in close association with a sericitized dike of granite porphyry. The schist had not only been intruded by the dike but had apparently been fractured by it. Stibnite has been deposited on the surface of the dike and occurs as small veins and lenticular masses up to several pounds in weight in the schist. The stibnite at this locality is apparently in close genetic association with the granite porphyry.

A ledge carrying stibnite has also been found on Caribou Creek, in the Kantishna district.[3] Here the stibnite is intergrown with quartz in a vein lying parallel to the foliation of the country rock, which is a hornblende schist. Antimony-bearing ledges are known to have been found on Seward Peninsula, in the Nome River basin and on upper Fish River. On Manila Creek, a tributary of Nome River, there is a well-defined quartz vein through which stibnite is disseminated. The country rock is schist, but the vein occurs near a limestone-schist contact.[4] At the Omilak mine,[5] in the Fish River basin, stibnite occurs in a shattered zone in a limestone bedrock. This limestone, which forms a belt almost one-fourth of a mile wide, bounded on both sides by schist, is cut by an altered intrusive rock.

OTHER METALLIC MINERALS.

Nickel and cobalt deposits have been reported by prospectors, but in no samples tested by the Survey were these metals found in commercial quantities. A small amount of nickel and traces of cobalt were found by the analyses of some pyrrhotite ores from the Ketchi-

[1] Grant, U. S., and Higgins, D. F., Preliminary report on the mineral resources of the southern part of Kenai Peninsula: Bull. U. S. Geol. Survey No. 442, 1910, p. 178.

[2] Prindle, L. M., Auriferous quartz veins in the Fairbanks district: Bull. U. S. Geol. Survey No. 442, 1910, p. 221.

[3] Prindle, L. M., The Bonnifield and Kantishna regions: Bull. U. S. Geol. Survey No. 314, 1907, p. 219.

[4] Moffit, F. H., The Nome region: Bull. U. S. Geol. Survey No. 314, 1907, p. 139.

[5] Smith, P. S., and Eakin, H. M., A geologic reconnaissance in southeastern Seward Peninsula and the Norton Bay-Nulato region: Bull. U. S. Geol. Survey No. 449, 1911, pp. 64-131.

kan district.[1] Similar tests on pyrrhotite ores from Prince William Sound revealed neither cobalt or nickel.

No commercial bodies of molybdenite have been found. In the Juneau district this mineral is found in some of the auriferous deposits which occur in the dioritic rocks, notably at the Treadwell mine. Molybdenite has also been found in quartz stringers which cut the sediments altered by igneous metamorphism adjacent to the Coast Range granite belt in the Ketchikan district. It has also been seen as an accessory mineral with the gold ores in other parts of Alaska.

A deposit of native bismuth on which a little development work has been done occurs on Charley Creek, tributary to Sinuk River, about 25 miles north of Nome. The bismuth occurs in two small quartz veins cutting a schist bedrock.

A cinnabar deposit was discovered near Kolmakof, on the Kuskokwim, many years ago and is a perennial source of attraction to prospectors. This deposit has not been studied by members of the Survey. Spurr,[2] however, notes that these veins cut shales of Mesozoic age, which have been intruded by acidic dikes. Cinnabar is found as an accessory mineral in some of the auriferous gravels. This mineral is very abundant in the concentrates from placer mining on Daniels Creek, about 60 miles east of Nome. While the bedrock source of this cinnabar has not been found, it evidently lies close at hand in a contact zone of schist and limestone.

A few minute grains of platinum have been found in some of the Alaskan gold placers, but nowhere in sufficient quantity to be of commercial importance.

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[1] Wright, C. W., and F. E., The Ketchikan and Wrangell mining districts, Alaska: Bull. U. S. Geol. Survey No. 347, 1908, p. 87.

[2] Spurr, J. E., A reconnaissance in southwestern Alaska: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 261-262.