# THE METALLIFEROUS DEPOSITS OF CHITINA VALLEY.

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## INTRODUCTION.

The mineral deposits of the Copper River basin, particularly of Chitina Valley, have been described from time to time during a period of many years in papers of the United States Geological Survey and in the scientific and technical journals. These papers are widely scattered in many publications, some of them long out of print, so that much of the information they contain is no longer generally available. The writer expects to collect into a single paper the general facts of the geology and mineral resources of this region, but meantime it appears desirable, especially for the benefit of those who wish to search for new mineral deposits or to test the value of known deposits, to summarize briefly the mode of occurrence of the valuable minerals so far discovered and to point out their relation to the geologic formations and structure. This paper is intended to present such a summary. It deals primarily with Chitina Valley but contains some references to adjoining districts. Attention is given mostly to minerals and mineral deposits that are already of economic importance.

Copper, gold, and silver are the only commercially valuable minerals that have yet been produced in the district under consideration. They are named in the order of the money value of the metal already mined, and the value of the copper far exceeds that of the gold and silver. Both copper and gold are mined for themselves alone, but silver is produced almost wholly in connection with the mining of copper, although a much smaller quantity is obtained from the gold placers and a single silver-gold vein. Gold is produced chiefly from placer gravels, where it is commonly found with considerable native copper and a small amount of silver. It is also obtained from the gold-silver vein mentioned.

## GENERAL GEOLOGY.

The rocks of Chitina Valley are prevailingly sedimentary rocks, such as limestone, shale, conglomerate, sandstone, and chert, but include also intrusive rocks and a great succession of lava flows.

The oldest known rocks of the district are included in the Strelna formation, probably of Mississippian age, which occupies much of the main valley of Chitina River. They comprise shale or slate, limestone, chert, tuff, and basic lava flows intruded by granular igneous rocks, including granodiorite, diorite, and gabbro. Both copper and gold are found in some of the rocks of this formation.

Overlying the Strelna formation is the Nikolai greenstone, a widespread succession of basic lava flows with a total thickness of not less than 4,000 feet. The structural relation of the Nikolai greenstone to the Strelna formation has not been understood but from observations made in 1922 appears to be that of unconformity, possibly without discordance in dip—that is, the Strelna formation may have undergone erosion without deformation before the Nikolai basalt flows were poured out. The precise age of the Nikolai greenstone, furthermore, is not definitely known but is indicated within limits by the fact that the greenstone overlies Permian sandstone and conglomerate in the valley of Chitistone River and underlies Upper Triassic limestone in many places. Copper in small amounts is found almost everywhere in the Nikolai greenstone, a fact that may be of great significance in connection with the origin of the copper deposits.

The Nikolai greenstone is overlain, without apparent unconformity, by a great thickness of Upper Triassic sediments, the lower part of which consists of limestone, long known as the Chitistone limestone, and the upper part of shale, known as the McCarthy shale. Since 1917, however, the name Nizina limestone has been applied to the upper two-fifths or thin-bedded part of the original Chitistone limestone of the Nizina district, and the name Chitistone limestone has been restricted to the lower three-fifths, consisting of more massive beds. The name Kuskulana formation has also been used to cover the Nizina limestone and the McCarthy shale of the Kotsina-Kuskulana district. The Chitistone limestone, in which the great copper ore bodies of Kennicott are found, has a thickness of about 1,800 feet, and the overlying Nizina limestone a thickness of about 1,200 feet. Their combined thickness is probably 500 feet greater than the thickness of the overlying McCarthy shale.

The Triassic and older rocks were folded, subjected to erosion for a long period, and then submerged in whole or in part below the sea, after which there were deposited on them conglomerate, sandstone, limestone, shale, volcanic tuffs, and lava flows ranging in age from Middle Jurassic to Tertiary. These later rocks, with the exception of the Cretaceous shale, which is widely developed in the Nizina district, are nowhere known to contain mineral deposits except a few thin beds of lignitic coal and need not be considered further.

The sedimentary beds were invaded by granodioritic intrusives showing a wide range in age, texture, and color. In some places these intrusives have played an important part in the formation of metalliferous deposits.

Sometime after the formation of the youngest of the consolidated bedded rocks of the district—that is, the Tertiary sediments and volcanic beds—the region was elevated above the sea. This elevation did not take place suddenly but required a long time. It renewed the processes of erosion and gave opportunity for the streams to carve their valleys deep into the elevated sedimentary and volcanic beds, producing a rugged mountainous district with relief comparable to that of the present time. Such conditions accompanied by a less rigorous climate must have given rise to much more vigorous circulation of underground meteoric waters than is possible now or has been possible at any time since the beginning of glaciation, when the circulation of underground waters was practically stopped by ground temperatures lower than the freezing point of water. So far as the age of the metalliferous deposits, except the placer deposits, is known, they were all formed before the land took on its present form, and therefore many of them must have been subjected to chemical changes by circulating waters in preglacial time. Since glaciation began the changes in the ore deposits have been mechanical rather than chemical, consisting of such changes as would be brought about by movements in the rocks or by glacial erosion and the breaking up of deposits by frost and atmospheric weathering. Postglacial oxidation, except of a superficial kind, seems to be entirely lacking.

The topography of the district owes its present aspect in considerable measure to glaciation. With little doubt the major topographic features and most of the present drainage lines were established in preglacial time, but they have been modified by ice erosion and the deposition of ice-borne débris and the loose material carried by glacial waters. Although the glaciers are now greatly reduced, this period of glacial activity is not yet ended. It is not necessary to discuss in further detail the geologic history of the district, yet it should be borne in mind that the glacial epoch followed a much longer period of land erosion, which went on under milder climatic conditions than prevail at present, and that during this period of erosion most if not all of the metalliferous deposits were undergoing chemical changes, which were stopped by the cold and ice of the glacial epoch. This fact has an important bearing on the character of ore bodies such as those at Kennicott.

## AGE OF MINERALIZATION.

A study of the ore deposits in connection with the general geology of the district leads to the conclusion that the ore bodies are to be referred to two or more periods of formation. The age of different ore bodies can not be stated definitely, but certain limitations of age can be determined. Gold, silver, or copper is found in the Strelna formation, in the Nikolai greenstone, and in the shale overlying the McCarthy shale—that is, in rocks that range in age from Mississippian (lower Carboniferous) to Upper Cretaceous. The age of the inclosing country rocks, however, tells little about the age of the mineral deposits except that the country rocks are the older. The mineral deposits may have been formed at some one particular period after the rocks were formed, or they may have been formed at different times. Moreover, the formation of the ore bodies was not a sudden process, completed at a stroke, but took place slowly as the mineral-bearing waters made their way through the devious openings in the rocks and gradually deposited their metal content.

A number of bodies of igneous rock occur in Kuskulana Valley that were intruded into Triassic and older rocks but not into sediments overlying the Triassic rocks. These intrusive bodies consist of granodiorite or closely related rocks. In places they are themselves mineralized with copper sulphides, and in places they have produced contact-metamorphic deposits of copper and other metallic minerals at the borders of the rocks which they invaded. Several large veins of magnetite were formed in this manner on MacDougall Creek. Waterworn pebbles of this magnetite have been found at the base of the Upper Jurassic (?) conglomerate that lies unconformably above the older sediments and the igneous intrusive at this place and furnish evidence that the mineralization here and probably near by on Berg Creek was later than Upper Triassic and earlier than Upper Jurassic.

Definite evidence for the age of the copper mineralization in the Nikolai greenstone and the Chitistone limestone is lacking. It may belong to either of the two periods already named or it may belong to a third distinct period. There is no reason known to the writer for supposing that the original copper mineralization took place at different times rather than as one continuous process, though doubtless the copper ores were long in the making.

It is unnecessary for the purpose of this paper to enter into a discussion of the source of the copper in the copper deposits further than to state that they were probably deposited from hot ascending solutions. A most excellent statement concerning the source of the copper and the manner of its deposition has been made by Bateman and McLaughlin[1] as a result of a painstaking study of the ore deposits at Kennicott.

In the Nizina district the Upper Cretaceous shales are cut by many conspicuous dikes and sills of quartz diorite porphyry, and these dikes and sills are associated with veins of quartz carrying pyrite and free gold. Molybdenite is present, and probably stibnite. The creek gravels yield also galena, cinnabar, barite, and marcasite (?), but these minerals were not seen in the veins. It is evident from the age of the inclosing rocks that these minerals, or at least the veins carrying the gold, represent a period of metal deposition distinct from that previously mentioned.

## CHARACTER OF THE DEPOSITS.

For convenience in description the ore deposits will be considered under the headings copper, gold, and silver, although two or more of the metals occur together at different localities and therefore the divisions overlap one another in some degree.

### COPPER.

Copper is found in Chitina Valley as lodes of native copper and compounds of copper and as native copper in placer gravels. The copper minerals that have been recognized in the lode deposits include antlerite, arsenates of copper, bornite, brochantite (?), chalcanthite, chalcopyrite, chalcocite, covellite, cuprite, enargite, freibergite (?), luzonite, malachite, native copper, tennantite, and tetrahedrite. These minerals are by no means equally abundant or everywhere present. As measured by past production, chalcocite, covellite, enargite, and the carbonates azurite and malachite should be placed first, and the others, except possibly bornite, should be regarded as of little interest to the miner.

The copper lode deposits may be best considered by classifying them in accordance with the kind of rock in which they are found. Two classes are thus distinguished—copper deposits in limestone and copper deposits in lava flows, particularly in the Nikolai greenstone. These two classes differ in mineral associations and to a certain degree in form, but they are believed to belong to the same period of mineralization and to be different expressions of a single process of mineral deposition, owing their distinguishing features to the chemical and physical character of the inclosing rock rather than to differences in chemical composition of the original mineral solutions.

[1] Bateman, A. M., and McLaughlin, D. H., Geology of the ore deposits of Kennicott: Econ. Geology, vol. 15, No. 1, January, 1920.

The largest and best-known examples of copper deposits in limestone are those of Kennicott, which will therefore be described briefly as typical of this class of deposits. As given by Bateman,[2] the ore minerals at Kennicott, except those obviously due to oxidation, are chalcocite, covellite, enargite, bornite, chalcopyrite, luzonite, tennantite, pyrite, sphalerite, and galena. No gangue minerals are present. To this list should be added other minerals that are plainly due to oxidation processes. They are malachite, limonite, covellite, antlerite, azurite, arsenates of copper, chalcanthite, cuprite, and possibly brochantite. The minerals in both lists are given in the order of their abundance. It is estimated by Bateman that the sulphide ores make up approximately 75 per cent of the ores mined and that of the sulphides chalcocite constitutes from 92 to 97 per cent, covellite from 2 to 5 per cent, and other sulphides less than 1 per cent. Besides copper the ores of Kennicott carry a considerable quantity of silver, which is recovered in smelting. Very little gold is present.

The ore bodies are in the lower beds of the Chitistone limestone, which here dips 23°–30° NE. and is separated from the underlying greenstone by a bed of red and green shale ranging in thickness from 4 to 7 feet. This shale is inconspicuous but is generally present throughout the district. The ore deposits, viewed in the large, have the form of elongated tabular bodies standing on edge with their long axes approximately parallel to the dip of the limestone-greenstone contact. A cross section made by a plane parallel to the strike and perpendicular to the bedding planes of the limestone shows that the ore bodies have the form of narrow wedges with the base down and the thin edge up. The position and form of the principal ore bodies are due to two systems of faults, one of which is vertical and almost parallel to the direction of dip of the limestone, the other inclined and parallel to the limestone beds. Other faults are present but need not be considered, as they were not involved in the formation of the ore bodies. The bedding or "flat" faults are at the base of the wedge-shaped ore bodies that occupy the vertical fissures. Bateman[3] says of the ore bodies:

> The average height of the main Bonanza vein from the base to the apex, measured normal to the incline, is about 210 feet in the upper levels and 150 on the lower levels. It has been followed for a distance of about 1,900 feet, measured along its base, and the width varies from 2 to 50 feet. The main Jumbo vein, exclusive of its enlargement at the flat fault, averages about 360 feet in height, from 2 to 60 feet in width, and has been followed down on its base for 1,500 feet.

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[2] Op. cit., pp. 35, 45.
[3] Op. cit., p. 30.

The figures for the extension of these ore bodies down the dip of the limestone are now greater than when the paper quoted was written.

The form of these ore bodies deserves special attention, because of its possible significance to the prospector. Bateman has shown by careful surveys in the Bonanza mine that the ore bodies trend parallel to the axis of a gentle transverse downfold in the Chitistone limestone, a fold whose axis pitches to the northeast, in approximately the same direction as the dip of the major folds. He suggests that the wedge-shaped form of the ore bodies results from this transverse folding, by which the beds of greater radius on the outside of the fold were under tension and tended to separate along planes of fracture, whereas the beds of shorter radius nearer the center of the fold were under compression and tended to remain closed. Folding might well result in fracturing and the formation of wedge-shaped openings whose long dimensions were parallel to the axis of the folds and whose widest parts turned downward where the folds are synclinal or upward where they are anticlinal. At the Bonanza mine the transverse folding is synclinal, and the wide parts of the ore bodies that occupy the fractured limestone turn downward, as would be required by such a method of formation. The walls of the fractures may never have been separated more than enough to allow solutions to circulate, for the folding took place slowly, and the separation may have gone on no faster than the ores were deposited. The openings may also have been enlarged by solution as the water circulated through them.

The ore bodies are not so simple in form as the preceding description may suggest. As pointed out by Bateman,[4] the ore deposits at Kennicott form vein deposits, irregularly shaped massive replacement deposits, and stockworks in the limestone. Bateman further divides the replacement deposits into irregular massive deposits, veins, and disseminated deposits, with all gradations between.

These distinctions may be better understood if the folded beds of the Chitistone limestone and the greenstone are pictured as having been subjected to forces that produced faulting with an unknown amount of movement along planes of the limestone practically parallel to the bedding and vertical fractures approximately parallel to the strike of the beds. The joint planes and openings were not everywhere simple, clean-cut, and regular. The rock in places was broken by many irregular fractures. The ore-bearing solutions made their way in the main along vertical fractures just above the bedding-plane faults but entered all other openings to which they had access. The mineral content was deposited partly in open cavities but more often

[4] Op. cit., p. 20.

by a replacement of the limestone itself—that is, the limestone with which the solutions came into contact was taken into solution, and copper ores were deposited in place of the dissolved limestone. In some locations the replacement of the limestone is complete so that great masses of pure copper minerals occupy the space once filled by limestone. In other localities, as in the stockworks and disseminated deposits, the replacement has not proceeded so far, and limestone forms here a small or there a large part of the ore. Irregularities of thickness of the wedge-shaped vein deposits show that the replacement went on more rapidly at some points than at others. The forms of the ore bodies are therefore dependent on the accidents of fracturing in the limestone, the facility with which the circulating waters made their way through the openings, and the degree of completeness of replacement by copper minerals.

A common experience in mining these ores is to find that an ore body terminates abruptly or that a tiny stringer of copper minerals, apparently of no value whatever, if followed a sufficient distance opens out into a large mass of ore. It is therefore necessary to explore every indication of mineralization, for otherwise valuable ore may be missed.

The original copper deposits have undergone oxidation resulting from the chemical action of surface waters, which circulated through the ore bodies at a time preceding the beginning of glaciation but practically ceased to circulate when glaciation began. No difference in the amount of oxidation has been noticed as the mine workings were carried deeper into the mountains—that is, to the 1,750-foot level. As noted before, it is estimated that 25 per cent of the ore mined is oxidized.

No other ore bodies comparable in size with those at Kennicott are known in Chitina Valley, and none similar in size and richness have been found elsewhere. Small bodies similar to those at Kennicott, however, have been found at a number of places, as near by on McCarthy Creek and on Bowlder Creek; and although they have not yet proved to be of economic value, they offer encouragement for further prospecting.

The features of the Kennicott deposits that may be of assistance to prospectors and should be kept in mind are (1) that the only productive ore bodies so far found in the district are in the Chitistone limestone; (2) that gentle transverse downfolds or synclines in the Chitistone limestone should receive special attention, because the folding may have been accompanied by the production of fractures in the limestone favorable to the circulation of ore-bearing solutions; and (3) that the most insignificant veinlets of copper minerals in the limestone should not be neglected, for experience has shown that they may open out into large ore bodies.

It is not intended to imply that commercially valuable copper ores are unlikely to be found in the greenstone or that downfolds in the limestone are the only places favorable for ores. It can readily be seen that openings of the same nature as those described may be formed on the tops of anticlines, and that strong faults of almost any kind may furnish the opportunity for ore-bearing solutions to circulate. It is true, however, that copper deposits have not been found in the overlying Nizina limestone, which underlies the McCarthy shale.

Copper deposits in greenstone are found chiefly in the Nikolai greenstone but occur also at several localities in basaltic flows of the Strelna formation underlying the Nikolai greenstone. The latter deposits have not given much promise and for the most part resemble those in the younger flows. The copper deposits of the Nikolai greenstone are in part contact-metamorphic deposits and in part deposits produced by the action of heated circulating ground waters.

Contact-metamorphic deposits are known at two places in this region, both in Kuskulana Valley. The greenstone in the ridge between Clear and Porcupine creeks is intruded by a mass of granodiorite not readily distinguishable from the greenstone itself. Small quantities of sulphide minerals, chiefly pyrite and chalcopyrite, are nearly everywhere present in the intrusive rock, but near the contact with the greenstone the sulphides are much more abundant. The pyrite and chalcopyrite are associated with magnetite, hornblende, and pyroxene. They occur as veins and as disseminated deposits which in places form small high-grade deposits but in general are of low grade and could be mined only by handling a great quantity of country rock.

Contact-metamorphic deposits occur also on MacDougall Creek, where the geologic relations are complicated and somewhat obscure, but a large mass of light-colored quartz latite with associated porphyritic dikes was intruded into rocks that include Triassic limestone and shale and possibly some of the older rocks. Large bodies of magnetite were formed, and in places the country rock, especially the limestone, was silicified and garnetized. Veins containing pyrite and chalcopyrite cut the country rock in this vicinity and apparently represent part of the mineralization brought about by the intrusion. Some of these veins, such as that of the North Midas mine, contain gold and a considerable quantity of silver.

It is characteristic of contact-metamorphic deposits that they are irregular in form and variable in mineral content, so that the mining of such deposits often presents more uncertainties than that of vein deposits. Development work on MacDougall Creek has not met with encouraging results, and work on Clear Creek has only disclosed a large body of low-grade material that can not be mined profitably under present conditions.

The more common copper deposits in the greenstone have the form of veins, stockworks, disseminated deposits, and amygdules or fillings of the gas cavities of basaltic flows. The term " stringer lodes " has been applied to them. A brief consideration of the character and structure of the greenstone will assist in understanding the form of these copper deposits.

The Nikolai greenstone, which contains most of these deposits, includes a great thickness of basaltic lava flows covering a large area in Chitina Valley and possibly having a much greater extent than is yet known. Individual flows range in thickness from a few feet to several hundred feet, but the regularity of these flows is such as to give the greenstone the appearance of bedded sedimentary rock. Mineralogically and texturally the basalt shows great similarity throughout the succession of flows and also in the individual flows. As a rule the tops and bottoms of flows are not distinguishable by textural features. Scoriaceous surfaces are not recognized, and gas cavities are not especially characteristic of the tops of the flows, although in a few localities this feature was noted.

The lava flows form hard, resistant rocks, and although everywhere chemically altered from their original condition, they are much less soluble than the overlying limestone. They have been folded in the same way and at the same time as the limestone but have reacted differently to the deforming forces. They have accommodated themselves to deformation in part by bending and faulting but still more by breaking into innumerable blocks of various sizes bounded by fracture planes whose slickensided surfaces show movement of one block on another, even where well-defined fault planes are not present. Such fractures provided most intricate channels for the circulation of mineral-bearing waters.

In the greenstone deposits are found bornite, chalcopyrite, pyrite, chalcocite, malachite, azurite, native copper, silver-bearing tetrahedrite (possibly in part freibergite), cuprite, covellite, and chalcanthite, of which bornite, chalcopyrite, chalcocite, and pyrite are most abundant. The copper minerals are accompanied in many places by quartz, epidote, and calcite.

A study of a large number of prospects in the Kotsina-Kuskulana district led to a separation of the copper sulphides in greenstone into the following classes:[5]

Argentiferous tetrahedrite ores.
Chalcocite ores.
Bornite and bornite-chalcocite ores.
Bornite-chalcopyrite ores.
Pyrite-chalcopyrite ores.

These associations of minerals apparently represent the original character of the deposits, and in the few places where other copper minerals were found with the minerals in one of the above-named classes it was fairly certain that the extra minerals were of later origin.

A few of the copper deposits take the form of well-defined veins of considerable extent. Such veins are found in the Strelna formation as well as in the Nikolai greenstone. By far the greater number of copper deposits are of the stockwork and disseminated types. Mineral-bearing solutions in circulating through the greenstone along available openings have deposited copper minerals and to a certain extent have replaced the greenstone. These solutions also penetrated into the greenstone walls adjacent to the channels and deposited copper minerals that have no evident connection with the main veins. In this way copper deposits were formed that are notably irregular in form and uncertain in extent.

The copper filling in the vesicles of lavas is chiefly native copper. These amygdaloidal copper deposits are found at several localities, of which the best known is that on Shower Gulch, at the head of Kotsina River. Native copper is also found as thin sheets or as slugs and irregularly shaped masses mingled with quartz in veins in the greenstone. In such places it appears to have resulted from the alteration of earlier copper minerals. A third mode of occurrence of native copper is with gold and silver in some of the stream gravels. Placer copper has been found wherever streams cutting rocks of the Nikolai greenstone have been worked for gold and is present in pieces that range in size from small shot to masses of several hundred pounds or at one locality even more than a ton. In the Nizina district copper has been recovered from the gold placers and shipped to the smelters but has not been found in paying quantities in bedrock.

Silver-bearing tetrahedrite is known at only one locality on Kotsina River, where it occurs in a vein with chalcopyrite, galena, and a small amount of bismuth-bearing mineral, probably bismuthinite.

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[5] Moffit, F. H., and Mertie, J. B., The Kotsina-Kuskulana district: U. S. Geol. Survey Bull. 745, p. 86, 1923.

The copper deposits in greenstone are believed to have undergone weathering and possibly alteration during the same period as the deposits in limestone. Like the deposits in limestone, they have not been shown by mining development to change in character as they are followed downward. No reason exists, therefore, for supposing that copper deposits exposed at the surface will become either richer or poorer below the surface. The surface exposures are dependent on the accidents of erosion, which may have progressed only so far as to expose the beginning of an ore body or which may have exposed a maximum cross section or removed all but the last traces of the body. The first two possibilities are well illustrated by the conditions at Kennicott. When the Bonanza mine was discovered a large section of the ore body was exposed at the surface, and hundreds of tons of high-grade ore that had been eroded from the exposed vein lay in the talus on each side of Bonanza Ridge. The deposit at the Jumbo mine, on the other hand, was little more than indicated by surface exposures, and not until mining had proceeded for some time was the immense size of that ore body disclosed.

## GOLD.

Gold has been produced in Chitina Valley from both lode deposits and placers. The production from the lode deposits, however, is insignificant in comparison with that from the placers, and such gold as has been obtained from lodes so far has cost more than its market value.

Gold-bearing veins are known in rocks of the Strelna formation; in the Valdez group, which lies south of and adjacent to rocks that are correlated with the Strelna formation in Hanagita Valley and the mountains between Copper River and Tonsina Lake; and in the Cretaceous shales of the Nizina district.

It is believed that the gold was deposited during at least two periods, of which one was earlier than that of the Upper Jurassic (?) rocks east of Kuskulana River and the other necessarily later than that of the Upper Cretaceous shales inclosing the veins of the Nizina district. Possibly other periods are also represented. Evidence for a period of gold deposition earlier than Upper Jurassic is not complete. Possibly the gold-silver veins of Berg Creek are not connected with the contact-metamorphic copper deposits near by on MacDougall Creek but are of later age. If this is true the gold deposits may eventually prove to belong to only one period.

All the gold veins so far discovered occur in rocks that are cut by granodioritic intrusives, and although the dependence of one on the other has not been demonstrated, the association is thought to be significant. Mertie [6] has shown the existence of such a relation in the Yukon and Kuskokwim regions, and its existence in this district is probable.

The gold-bearing veins have not been explored sufficiently to warrant a separation into distinct types, yet differences in manner of occurrence are apparent. The silver-gold deposits of Berg Creek have been mentioned. They occur as veins of iron and copper sulphides with a little quartz and are found in a body of porphyritic granodiorite. Pyrite is the prevailing sulphide, but chalcopyrite is present and shows an iridescent stain where weathered. Mill tests have shown that the richest ore comes from oxidized parts of the veins and that silver predominates largely in quantity over the gold.

A promising gold vein on Benito Creek near the trail from Strelna to Elliott Creek consists of quartz and a subordinate quantity of coarsely crystalline calcite, with which are associated chalcopyrite, bornite, pyrite, and free gold. Stains of azurite and malachite have resulted from the oxidation of the copper sulphides. This vein is in rocks of the Strelna formation.

The gold-bearing veins of the Valdez group, such as those found along the lower Copper River and the Valdez road, consist of quartz carrying arsenopyrite and free gold. Galena is present in places. These veins cut slate and graywacke and are associated with light-colored dikes of diorite porphyry. Some of them have yielded small quantities of rich gold ore, but development work has always shown that the high-grade ore is irregularly distributed. Although such ores have furnished fine specimens, no considerable quantity of gold has yet been found, and none of the deposits have been worked profitably.

The gold-quartz veins in the Cretaceous shales of the Nizina district contain pyrite and free gold with locally some molybdenite and probably some stibnite. Galena, cinnabar, barite, and marcasite may also be present, for they are found in the creek gravels. A small vein on Rex Creek was found to consist of quartz with molybdenite and pyrite and assayed 0.18 ounce of gold and 12.80 ounces of silver to the ton. A dike rock near this vein seemed little altered and contained pyrite with traces of both gold and silver. These occurrences are cited to show the evidence for a local source of some of the gold in the creek gravels and to indicate that prospecting for gold lodes may be justified.

Gold placers in this district have been mined profitably only in the drainage basins of Dan and Chititu creeks and on a tributary to the north branch of Bremner River south of Chitina Valley.

[6] Mertie, J. B., The occurrence of metalliferous deposits in the Yukon and Kuskokwim regions: U. S. Geol. Survey Bull. 739, pp. 149–165, 1922.

In the Dan-Chititu area the placer gold has been derived from gold-bearing veins in the Cretaceous shales, and in the Bremner area from veins in rocks of the Valdez group, some of which have been prospected.

The gold of Dan and Chititu creeks and their tributaries is associated with native copper and native silver. Native copper, however, does not accompany the gold on tributaries like the upper part of Rex Creek, where the Nikolai greenstone is not exposed and where foreign gravels derived from the greenstone farther east in Chitina Valley were not brought in by the glaciers.

One feature of the gold placers that deserves special consideration is that the most productive gravel is that in which a concentration of gold from bench gravel has taken place. The deep bench gravel of both Dan and Chititu creeks contains gold. Prospecting tunnels have been driven in numerous places to test this gravel, and it has been mined on both Dan and Chititu creeks. The bench gravel itself may contain older creek gravel with concentrations of gold. A well-defined old channel considerably above the present creek level follows the mountain slope south of Dan Creek. Its buried creek gravel carries gold and has been mined in a small way for a number of years.

Most of the gold in the bench gravel is concentrated near bedrock or in places on "false bedrock" at different distances above true bedrock. It is only these richer parts of the bench gravel that have been mined. Possibly the upper part of the bench gravel is too poor to be mined for its own gold content, so that the cost of its removal must be borne by the lower and richer gravel when the time comes for exploiting the benches.

The deep bench gravel was trenched and parts of it were removed or are being removed by the present streams. During this process the gold in the reworked gravel received a further concentration, with the result that the creek gravel is much enriched. Reconcentration of gold from the deep bench gravel into present stream gravel is common in many parts of Alaska, and the knowledge of this process should lead the prospector to give special attention to those localities where streams are seen to be reworking bench gravel.

## SILVER.

The occurrence of silver has been mentioned in considering copper and gold. Silver occurs in this district in association with the copper ores of Kennicott, where it is present to the amount of 14 to 16 ounces to the ton of high-grade ore; in the pyrite-chalcopyrite veins on Berg Creek; in the tetrahedrite veins on Kotsina River; and as native silver associated with native copper and gold in the gold placers of the Nizina district. Samples taken from gold-bearing veins in different parts of the district commonly contain some silver.

For the purpose of this paper it is not necessary to discuss the silver recovered in smelting the copper ores of Kennicott, as that is plainly a by-product of copper mining.

The claims on Berg Creek were staked and prospected for copper, but the veins now being mined were found on exploration to be worth more in gold and silver than in copper. Later, when the mill was started, it was learned that silver predominated largely in quantity over the gold.

Silver is the only metal in the silver-bearing tetrahedrite veins of Kotsina River that may have a commercial value, but exploration of the veins has not progressed to the stage where their value has been demonstrated. The veins are apparently in rocks of the Strelna formation but are close to the Nikolai greenstone and not more than a third of a mile from a mass of granodiorite which intrudes the Strelna rocks. The country rock inclosing the deposits is much shattered and faulted. The veins consist of a quartz gangue containing tetrahedrite, galena, azurite, and malachite. Bismuth is present in tiny veinlets of bismuthinite (?) cutting the tetrahedrite. No similar veins have been found elsewhere in Chitina Valley.

Nuggets of silver and also of copper and silver ("half breeds") are frequently found in the sluice boxes on Dan and Chititu creeks. One of the largest silver nuggets from the Nizina district known to the writer was found on Chititu Creek and consisted of a mass of native silver and quartz weighing 7 pounds. Other large nuggets have been found, and some of them may have been even larger than the one mentioned. Silver is not likely to be produced from placers in this district except as a by-product in the mining of placer gold. No evidence is known to indicate that silver is anywhere present in commercial placers. Doubtless the copper will be sought in the placer gravel before silver, if it ever becomes profitable to mine either metal where gold is not present.

## SUMMARY.

Copper, gold, and silver are being mined in Chitina Valley. Practically all the copper so far produced has come from deposits in the Chitistone limestone at Kennicott. Practically all the gold has been taken from the gold placers of Dan and Chititu creeks. Silver is an important constituent of the ores from Kennicott, is present in the gold placers, and has been recovered from one vein deposit.

The only producing copper mine is in the basal beds of the Chitistone limestone, but copper deposits also occur in the basaltic lava flows of the Nikolai greenstone and in similar basaltic lavas of the

Strelna formation, which underlies the Nikolai. Experience gained from mining and from a consideration of the known occurrences of copper minerals indicates that the most favorable horizon in the Chitistone limestone for copper deposits is in the beds near the Nikolai greenstone. This conclusion, however, is not universally applicable, for the original outcrop of the Mother Lode mine, now being exploited by the Kennecott Corporation, was many hundreds of feet stratigraphically above the base of the limestone, possibly near the middle of the formation. A few copper deposits in greenstone occur as well-defined fissure veins, but by far the greater number were formed by the deposition of copper minerals in preexisting openings or by the replacement of the wall rock along irregular and intricate systems of fractures.

Gold and silver are found in the formations ranging from the tuff, limestone, shale, and basalt flows of the Strelna formation to the Cretaceous shales. Gold is produced chiefly from placer gravel, and silver from the silver-bearing copper ores of Kennicott, but both metals are being produced from vein deposits, so that the expectation of finding other gold-silver veins is reasonable. The probable dependence of gold-silver mineralization on the intrusion of granodioritic rocks should be kept in mind in prospecting for placer deposits as well as for veins.

Prospectors searching for copper or gold lodes in this district should not expect a necessary or probable increase in the value of ore deposits at depth, for in general the original zone of oxidation and enrichment was largely removed during the period of intense glaciation. The depth of the ore body and the vertical distribution of high-grade ore are likely to depend primarily on the accidents of erosion. The richest part of the lode is as likely to be exposed at the surface as the poorest.

Furthermore, the prospector for placer gold should pay particular attention to deep gravel which is being reworked by present streams, for this process at many Alaskan localities has resulted in a reconcentration of low-grade deposits and the formation of valuable placers.