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GEOLOGY AND MINERAL RESOURCES

OF THE

NIZINA DISTRICT, ALASKA

BY

FRED H. MOFFIT

AND

STEPHEN R. CAPPS

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PREFACE.

By Alfred H. Brooks.

The completion in 1908 of the reconnaissance surveys[a] of the two copper belts lying north and south of the Wrangell Mountains paved the way for more detailed investigations. As the southern or Chitina copper belt will be the first one to be developed, it was appropriate to begin the detailed investigation in this field. The funds available for this work made it possible to survey only a part of the Chitina belt, and after careful consideration it was decided to take up the work in the Nizina district. This conclusion was based on three considerations: (1) The information available indicated that the Nizina district afforded the best opportunities for solving the general geologic problems relating to the entire copper belt; (2) the mining developments of this part of the district were more extensive than elsewhere in the belt, which gave both better opportunities for observations on the occurrence of the ores and greater promise of soon reaching a productive basis; (3) investigation of this field made it possible to cover a placer district long productive in a small way and giving promise of larger output.

The descriptions set forth in this report apply to only about one-fourth of the Chitina copper belt, but the conclusions advanced as to occurrence of the ores will, it is believed, have value to the entire district. If the developments in the Chitina Valley continue, as is expected, further surveys will be undertaken as soon as circumstances permit.

The cost of detailed geologic maps is much increased by the fact that they must be preceded by detailed topographic surveys. The Nizina region was surveyed by D. C. Witherspoon in 1908, and the resulting map, which is an excellent piece of work done under very adverse conditions, accompanies this report (Pl. II, in pocket) and adds much to its value.

[a] Moffit, F. H., and Maddren, A. G., The mineral resources of the Kotsina-Chitina region, Alaska: Bull. U. S. Geol. Survey No. 374, 1909; Moffit, F. H., and Knopf, Adolph, The mineral resources of the Nabesna-White River district: Bull. U. S. Geol. Survey No. 417, 1910.

The general geology of this district as set forth in the report bears testimony to the accuracy of the observations and deductions of the earlier workers in this field. It is a significant fact that the stratigraphic subdivisions, suggested by Oscar Rohn, who did the pioneer work in this field, have found acceptance in the present analysis of the geologic sequence.

The most important conclusion bearing on the economic geology here presented is the fact that the copper-ore bodies appear to occur chiefly along a system of cross fractures which are at approximately right angles to the greenstone-limestone contact. These fractures occur along well-defined faults, at least one of which has been traced for a long distance. This may apply to the entire Chitina district and is worthy of consideration by the prospector.

These investigations also appear to indicate that the copper deposits are by no means confined to the immediate vicinity of the limestone-greenstone contact, as has usually been supposed. Though the most promising ore bodies thus far found do occur in this contact, evidence of strong mineralization has been found at a considerable distance from it. Another important fact brought out by this investigation is the occurrence of auriferous deposits in the Kennicott formation (Jurassic).

This report, although far more complete than any other report previously published on the district, is by no means exhaustive. With the progress of mining many facts will be ascertained which will make possible more definite statements on the geology of the mineral deposits. If the district develops into a great copper producer, a detailed study of the mining geology should be undertaken similar to those made of many of the mining camps of the Western States.

GEOLOGY AND MINERAL RESOURCES OF THE NIZINA DISTRICT, ALASKA.

By Fred H. Moffit and Stephen R. Capps.

INTRODUCTION.

LOCATION AND AREA.

The Nizina district takes its name from Nizina River, a northern branch of Chitina River, and lies in the eastern part of the Copper River drainage basin. Its position with reference to the coast and the Canadian boundary is shown on Plate I, opposite. That portion of it to which the following descriptions are confined is included between parallels 61° 12′ and 61° 37′ north latitude and meridians 142° 22′ and 143° west longitude and is represented on the Nizina special map. (See Pl. II, in pocket.) The area mapped, however, is irregular in outline and only 300 square miles in extent, so that it comprises little more than one-half of the quadrangle indicated.

OUTLINE OF GEOGRAPHY, GEOLOGY, AND EXPLORATION.

Chitina River rises in the high snow-covered mountains northwest of Mount St. Elias and adjacent to the international boundary line and flows westward between the Chugach and the Wrangell mountains till it unites with Copper River at a point 100 miles from the coast. (See Pl. I.) Most of its waters, however, are derived through its northern tributaries from the snow fields of the Wrangell group. Nizina River is the largest of these tributaries. It drains the southeastern part of the Wrangell Mountains and a small part of the area between Chitina River and the head of White River. From its principal source in Nizina Glacier it flows southward for 15 miles and then turns abruptly to the west and continues in that direction 20 miles farther before joining the Chitina. It therefore has a length of 35 miles, all minor curves and irregularities of its course being disregarded. The big westward bend of the river lies almost in the center of the area covered by the Nizina special map.

The two branches of the Nizina, with Chitistone and Kennicott rivers, contribute much the greater part of its waters. It is therefore chiefly of glacial origin. All these streams are swift and heavily laden with glacial débris. They have floored their valleys with broad gravel flats, over which they migrate from side to side, sometimes in a single channel, sometimes in a network of channels, and, besides building up their flood plains by the addition of new material, they are continually cutting away and redepositing the material already laid down. The principal small streams shown on the Nizina special map are McCarthy Creek, a tributary of Kennicott River, and Dan, Chititu, and Young creeks, eastern tributaries of Nizina River. Their valleys do not show such profound glacial erosion as the main streams, for the ice masses that occupied them were smaller, yet they nevertheless underwent extensive glaciation. All are characterized by broad, open valleys at their heads and by rock canyons in their lower courses.

The Wrangell Mountains, although a more or less distinct group, merge into the St. Elias Range on the southeast and are not there sharply defined from them. They are limited on the south and west and partly on the north by the valleys of Chitina and Copper rivers, and are separated from the Nutzotin Mountains on the northeast by a depression extending from the head of Copper River to the head of White River. The group trends in a northwest-southeast direction and its length is approximately double its width. Its greatest diameter is about 100 miles. Half a dozen or more peaks of unusual beauty and size, ranging in height from 12,000 to 16,200 feet, rise above the rugged snow-covered mass about them, and from one of these, Mount Wrangell, the group received its name. The Wrangell Mountains were formed by the erosion of a great mass of Tertiary and Recent lavas piled up on an older surface of very considerable relief and having its greatest development in the neighborhood of Mount Wrangell and Mount Sanford. The southeastern limit of these younger flows is probably somewhere in the vicinity of Skolai Pass and Chitistone River, although it is possible that they may extend still farther to the east. Thus the Wrangell Mountains consist essentially of lava flows and are distinct in their origin from the other mountains about them, all of which are made up principally of deformed sedimentary beds. The area shown on the Nizina special map is on the border line between the volcanic flows of the Wrangell Mountains on the northwest and the older sedimentary formations of the Chugach and St. Elias mountains on the south and southeast, but the rock formations developed in the area are mostly of sedimentary origin.

The formations represented on the accompanying geologic map (Pl. III, in pocket) are shown in the section forming figure 1. At the base is the Nikolai greenstone, made up of a great but unknown thickness of basaltic lava flows, many of which are amygdaloidal. On the top of these flows rests the Chitistone limestone, which was deposited without any interruption of structural uniformity between it and the underlying rocks. Its thickness exceeds 3,000 feet. The lower part of the Chitistone formation consists of thick, massive beds of gray limestone, but toward the top the limestone beds become thinner and small shale beds appear in increasing amount till they finally predominate. The Chitistone limestone thus passes by transition through thin-bedded shales and limestones into a black shale with only occasional thin limestone beds. Much of the shale was removed by erosion before the deposition of the succeeding formation, so that its thickness, though in doubt, can not be less than several thousand feet. Both the Chitistone limestone and the conformably overlying shales (McCarthy shale) are of Upper Triassic age.

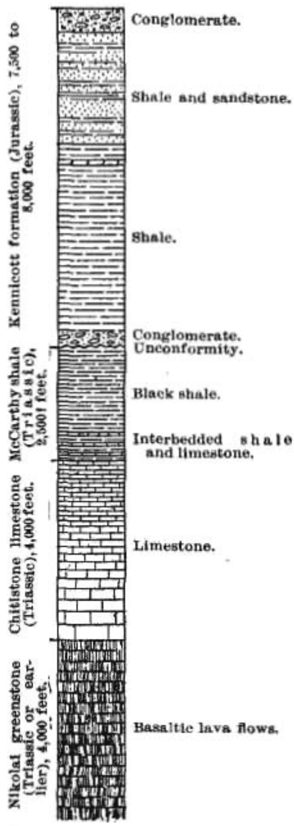


FIGURE 1.—Columnar section showing the formations represented on the geologic map of the Nizina district.

A period of uplift and erosion took place after the Triassic black shales were laid down and was not terminated till Upper Jurassic time, when deposition began once more. On the upturned edges of the Nikolai greenstone, the Chitistone limestone, and the overlying Triassic shales a great thickness of Upper Jurassic sediments (Kennicott formation) was deposited. They consist of conglomerate, sandstone, and black shale, but the shale predominates greatly over the conglomerate and the sandstone. The Jurassic sediments attain a thickness of at least 7,500 feet. They are the youngest of the bed-rock formations exposed within the mapped area. The later deposits consist of Quaternary sands, gravel, and silt, most of which are intimately connected in origin with the recent glaciation of the country.

The Nizina district has been the scene of igneous activity from Paleozoic time to the present. A great quantity of quartz diorite porphyry in the form of sills and dikes was intruded into the Jurassic rocks, but for some reason these intrusives rarely appear in the underlying formations. In some places the porphyritic intrusives are so extensively developed that they predominate over the shale, and the shale appears only as great black masses caught up in the light-colored intrusive rock.

Folding in greater or less degree has taken place in all the formations mentioned, but is far more pronounced in the older ones, particularly the Triassic shales, than in the Jurassic sediments. Within the area of the Nizina special map the greenstone, limestone, and shale formations dip rather steeply to the northeast. The Jurassic rocks, on the other hand, are tilted to the southwest or lie in broad, flat folds. All have been faulted and show local displacements of very considerable extent.

The earliest references to the geology of the Chitina Valley are found in the accounts of exploring expeditions made by Allen in 1885 and by Schwatka and Hayes in 1891. Such accounts, from the nature of the expeditions, could give only very incomplete information. The investigations by Rohn in 1899, however, laid the foundations of our present knowledge of the geology of the region. He recognized the formations that have been described and proposed the names Nikolai, Chitistone, and Kennicott. He also applied the name McCarthy Creek shale to the shale formation overlying the Chitistone limestone; but this was not adopted by Schrader and Spencer in their later work, since they believed that the shale should be divided into a number of formations.[a]

In 1900 Schrader and Spencer carried on a much more extended investigation of the geology and mineral resources of the Chitina Valley, and at the same time a topographic reconnaissance map was made by Gerdine and Witherspoon which was used as a base for the geologic map. Two years later (1902) Mendenhall visited the Kotsina and the Elliott Creek copper prospects, in the western part of the Chitina Valley, and published also some brief statements concerning the Nizina gold placers, although he had no opportunity to examine them in person. No further geologic work in the Chitina region was undertaken by the Federal Government till 1907, when interest in the copper resources of the country led to an examination by Moffit and Maddren of all the copper prospects in the valley, which resulted in some additional information concerning its geology and the occurrence of both copper and gold. The importance of the district led to the preparation of the Nizina special map by Witherspoon in 1908 and to the detailed geologic investigations in 1909, whose results are described in this report.

Many notes on the copper prospects, particularly the Bonanza mine, have appeared in the daily press and in mining magazines, and although most of them had only a temporary value as news a

[a] Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, Alaska: Special publication U. S. Geol. Survey, 1901, note at bottom of page 32.

few are permanent contributions to the literature. An incomplete list of papers on the district follows:

ALLEN, Lieut. HENRY T. Report of an expedition to the Copper, Tanana, and Koyukuk rivers, in the Territory of Alaska, in the year 1885. Washington, Government Printing Office, 1887.

HAYES, C. WILLARD. An expedition through the Yukon district: Nat. Geog. Mag., vol. 4, 1892, pp. 117–162.

ROHN, OSCAR. A reconnaissance of the Chitina River and Skolai Mountains: Twenty-first Ann. Report U. S. Geol. Survey, pt. 2, 1900, pp. 393–440.

SCHRADER, FRANK C., and SPENCER, ARTHUR C. The geology and mineral resources of a portion of the Copper River district, Alaska: Special publication of the U. S. Geol. Survey, 1901.

MENDENHALL, WALTER C., and SCHRADER, FRANK C. The mineral resources of the Mount Wrangell district, Alaska: Prof. Paper U. S. Geol. Survey No. 15, 1903.

MENDENHALL, WALTER C. Geology of the central Copper River region, Alaska: Prof. Paper U. S. Geol. Survey No. 41, 1905.

MOFFIT, FRED H., and MADDREN, A. G. The mineral resources of the Kotsina and Chitina valleys, Copper River region: Bull. U. S. Geol. Survey No. 345, 1908, pp. 127–175. (This is a preliminary statement of results published in a more complete form in Bulletin 374.

KELLER, HERMAN A. The Copper River district, Alaska: Eng. and Min. Jour., vol. 85, No. 26, June, 1908, pp. 1273–1278.

MOFFIT, FRED H., and MADDREN, A. G. The Kotsina-Chitina region, Alaska: Bull. U. S. Geol. Survey No. 374, 1909.

The field work on which the present report and the geologic map are based was done between July 1 and September 10, 1909, or in a little less than seventy days. It was greatly aided by a previous knowledge of the region and by the earlier work of Schrader and Spencer, but the time available was too short to permit an excursion up Nizina River to determine the relation between the Triassic and the Paleozoic sediments on Skolai Creek, or to make a careful study of the Kennicott formation south of Young Creek. Both localities merit careful investigation because of the light they may throw on the stratigraphy of the region. The chapter in this report dealing with the Quaternary system was written by Mr. Capps, who also did the office work on the geologic map. The task of preparing the remainder of the description of general geology and of economic geology fell to the senior author.

CLIMATE.

The climate of Chitina Valley is pleasanter in many ways than that of the Pacific coast region of Alaska. Temperature variations are far greater, but the precipitation is less and the number of cloudy, disagreeable days is very much smaller. No continuous records of temperature and precipitation are at hand, and it is probable that none have been kept, although observations for parts of several years have been made at Kennicott and were made available through the kindness of Mr. Stephen Birch.

The Copper River region, of which Chitina Valley is a part, as has been stated previously, is separated from the Pacific coast by a broad belt of mountains nearly 50 miles across and ranging in height from 6,000 to 10,000 feet. This belt is broken only by the narrow canyon-like valley of the lower Copper River, and by its influence on the warm moisture-laden air of the Pacific it becomes an important factor in the climate of Copper and Chitina basins. Another factor of importance is the still loftier Wrangell group of mountains on the north.

The seasons of Copper River basin are a long winter and a short summer, separated by a still shorter spring and fall. Spring comes sooner in the upper Chitina Valley than in the Copper River valley proper, as is shown by the earlier breaking up of the ice. Snow goes from the valley bottoms by the middle of May and from the lower hills by the first of June, but enough remains on the mountain sides till the first or middle of July to hinder prospecting. The summer climate resembles that of some of our Northern States in late spring. Frosts are not expected from the middle of June to the middle of July, but by the first of September the snow line begins to descend on the mountain sides. After the spring break-up the volume of water in the streams, particularly those fed by snow fields and glaciers, gradually increases until it reaches a maximum about the middle of July; it then decreases rapidly as the cooler nights come on. The July period of high water is not the result of increased precipitation but of the warm weather and the bright sun on the snow fields. Cloudy days always make a very appreciable difference in the daily rise of the glacier streams. Sometimes, however, the rivers are flooded by unusually heavy rains and occasionally in winter by the breaking out of water confined in the glaciers. This took place in the Kennicott Glacier early in 1909. During a period of unusually cold weather the outlet of the subglacial stream known as the "pot-hole" was closed and the water backed up under the glacier till the pressure was so great that the ice could not resist it. The water burst forth from a new outlet and flooded the Kennicott and Chitina rivers, tearing up the ice and piling it in confusion. Fortunately no one was freighting on the river, and the new ice which formed afterward gave the best sledding ever known by freighters on the Chitina. A similar flood caused by the breaking out of confined waters from Nizina Glacier took place a few years previously. The high water of July makes the fording of Nizina River difficult and at times dangerous, but this difficulty decreases in August, and by the first of September it is ended. Temperatures low enough to allow standing water to freeze are usual in the latter part of August, and early in September the glaciers cease to be active and the streams are clear and low.

Temperatures of 30°, 40°, or even 50° below zero are experienced in winter, and the snowfall is heavy, although much less than on the coast.

Observations at Kennicott, at the mouth of National Creek, and at the Bonanza mine, a little more than 2½ miles away and 4,000 feet higher, showed that the temperature at the mine during the coldest weather was always considerably higher than at the lower camp.

The winter of 1908–9 was unusual because of its low temperatures and light snowfall. It resulted from these conditions that the streams were in places frozen to the bottom, and the water, breaking out above, ran down over the top and froze to a great thickness. Some of the so-called glaciers on Chititu Creek had a thickness of 15 or 20 feet and did not melt away till early in the following July, thus seriously interfering with placer mining. Such conditions are common enough in the streams of northern Alaska but are unusual in the Nizina district.

VEGETATION.

In this region, as in many other parts of Alaska, vegetation flourishes in a way that would be surprising to those who think of the country only as a region of continual cold and ice. The growing season is short, but the summer days are warm and much longer than in lower latitudes, so that in the few favorable weeks plants grow rapidly. Grass comes up as soon as the snow goes and by the first or middle of June there is good feed for horses in favorable places. It is not abundant in the lower valley bottoms, even in midsummer, and the best of it is found at or above timber line. There is good feed in the upper part of all the small valleys. A small leguminous plant, locally called "pea vine," grows on the gravel bars and in the fall and late summer makes excellent forage. It is nourishing, and horses are so fond of it that they will leave almost anything else to get it. Grass loses its nourishing qualities as soon as the frost strikes it, and for this reason miners and prospectors start their horses to the coast about the first of September.

All the lower mountain slopes of the Nizina district and all the valley bottoms except the flood plains of streams are covered with spruce timber. The upper limit of timber ranges from 2,500 to 4,000 feet above sea and is highest on the gentle and rounded slopes away from the glaciers, such as the south slope of the ridge west of Rex Creek and on Sourdough Hill. Timber suitable for lumber grows on the lower ground. The best of it is found on the flats south of Nizina River, from Dan Creek to Young Creek, in the drier ground at the base of the hill slopes. Some of the trees reach a diameter of 18 inches and are tall enough to furnish two 16-foot cuts. Besides the spruce, there are cottonwood and birch, but these have little value for lumber. A heavy growth of alders is usually found about timber line. Willows are present in the valleys, but are far less abundant in variety and amount than in northern Alaska. The "devilclub," so troublesome in the coast region, is found occasionally in the Nizina district also.

POPULATION.

During the early days of the Nizina gold excitement the white population of the district amounted to several hundred persons, but this number quickly decreased, as is usual in such stampedes. There are no accurate records of the number of early comers. Some of them were of the "hanger-on" class and stayed only long enough to learn that the district had little to offer them. The later population has been a variable one, but for the last two or three years it probably has not been far from 100. Most of this number were employed in the gold placers of Chititu and Dan creeks and the rest were prospecting for copper. With the completion of the railroad and the beginning of mining at Kennicott and the increased activity in the gold-producing streams that will come with better transportation the white population will increase. There is no permanent native population. Nizina River valley was the hunting ground of Chief Nikolai, and his house was near the mouth of Dan Creek, but since his death several years ago superstition has kept his followers from returning there until within the last two summers. The permanent dwellings of the Indians are on Copper River, where they spend most of the winter and where they fish in summer. It seems to have been the custom of many to leave the fishing ground only during the time of the fall hunting or in the trapping season.

TRANSPORTATION.

To provide satisfactory means and routes of transportation has been from the beginning the most serious difficulty the prospectors in Chitina Valley have had to meet. Up to the present time all supplies and equipment for the Nizina district have been brought from Valdez in winter by sled. The route usually followed in freighting is from Valdez to Tonsina over the Government trail, then by way of Tonsina, Copper, Chitina, and Nazina rivers to the destination. Occasionally, however, this route has been varied by crossing Marshall Pass at the head of Lowe River and following Tasnuna and Copper rivers to the mouth of the Chitina; but this latter route was given up because of the difficulties encountered on Tasnuna River and of the fact that the Government trail to Fairbanks is kept open all winter by the regular travel. The great advantage of the route lay in the ability to haul very heavy loads on the smooth ice of Copper River, thus saving time and horse feed, the two great items of expense, on this part of the trip. This route probably would have been used exclusively for freighting to Chitina Valley if a good trail down Tasnuna River had been available for travel.

The time consumed in carrying large outfits from Valdez to the Nizina district is from two to three months. The cost of freighting has varied from slightly less than 7 cents to 30 cents per pound, depending on the size of the outfit and the condition of the trail. The lower figure of cost is an exceptional one and is not possible under any other than the most favorable conditions. Probably about 10 cents per pound is an average cost for the larger companies when the trail is good.

Summer travel is over a route different from that followed in winter. The summer trail leaves the Government trail at Tonsina and crosses Copper River at the mouth of Tonsina River. From there it passes to the north side of Chitina Valley, entering the mountains by way of Kuskalana River and crossing Kuskalana and Fourth of July passes to Kennicott Glacier and River. No freighting is done on the summer trail, but the mail goes in over it twice each month.

Within the Nizina district trails connect the various camps and enable the miners to travel from one to another without serious difficulty, although there is little communication between them during the working season. The trails are all shown on the topographic map and need not be described in detail. The one most traveled is that over Sourdough Hill from McCarthy Creek to Chititu and Dan creeks. Because it is less swampy, it is used by many in preference to the lower trail around the west end of the hill, but the hill is steep and the climb is hard. One great difficulty with this trail is the necessity of fording Nizina River. A proposal to bridge the river at a point several miles below the present fording place will probably be carried out in the near future.

It is seen from the figures previously given that the cost of transportation is a heavy tax on all work done in the Nizina district. This expense has not only hindered copper prospecting but has delayed the installation of placer mining machinery also. This burden will be much lightened in a short time, however, for railroad communication with the coast is promised early in 1911. Construction work on the Copper River and Northwestern Railway was commenced under the present management at Cordova in 1908 and since that time has been pushed as rapidly as conditions permitted. In 1908 the tracks were advanced from Cordova to within 10 or 12 miles of Abercrombie Rapids, although the lower steel bridge over Copper River was not erected till the following spring. In 1909 the piers for a second bridge, at the river crossing between Childs

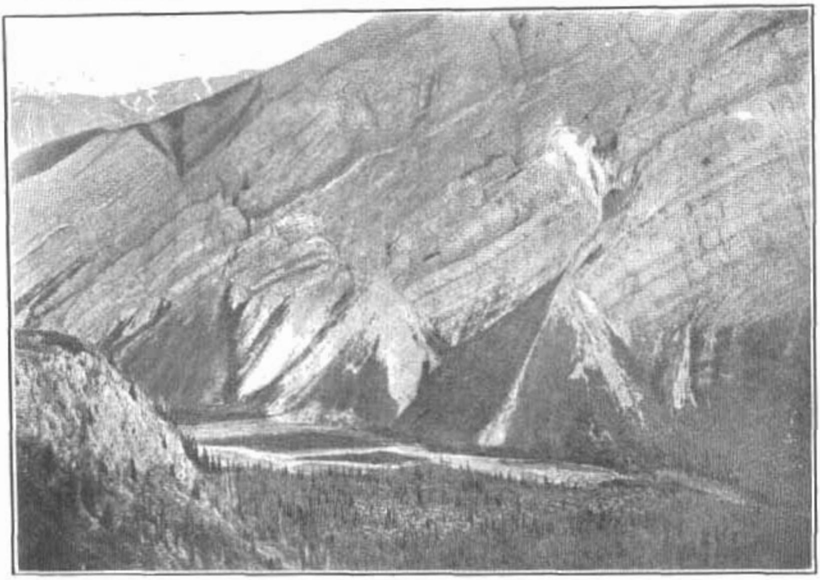
Glacier and Miles Glacier Lake, were built and the tracks were advanced to Tiekel River. With the completion of this part of the road most of the slow and difficult work was ended and there remained only 90 miles of track construction to reach Kennicott. This includes a third bridge over Copper River, between the mouths of Chitina and Kotsina rivers, where it is proposed to place a temporary pile bridge while the construction of piers for the permanent bridge is going on. The building of the railroad has not involved any unusually difficult construction problems for modern railroad engineering, and the greatest obstacles to operation will doubtless arise from weather conditions. Along Copper River the tracks are particularly exposed to obstruction by snowslides, and adequate provision for their protection will have to be made. Above Abercrombie Rapids the tracks follow the river bank on the débris-covered edge of Baird Glacier. The ice is overlain by a thin coating of loose rock and is overgrown with alders. It appears to have no motion, but it is probable that more or less melting goes on and that the tracks will require more attention and repair than in other places. Some have expressed uncertainty concerning the effect of the terrible winter winds that sweep down the lower part of Copper River valley and have even predicted that they would prevent the running of trains, but such difficulties have been overcome elsewhere and probably will be here. Railroad communication with the coast promises greater aid in the development of the Copper River valley than any other single enterprise yet undertaken.

TOPOGRAPHY.

RELIEF.

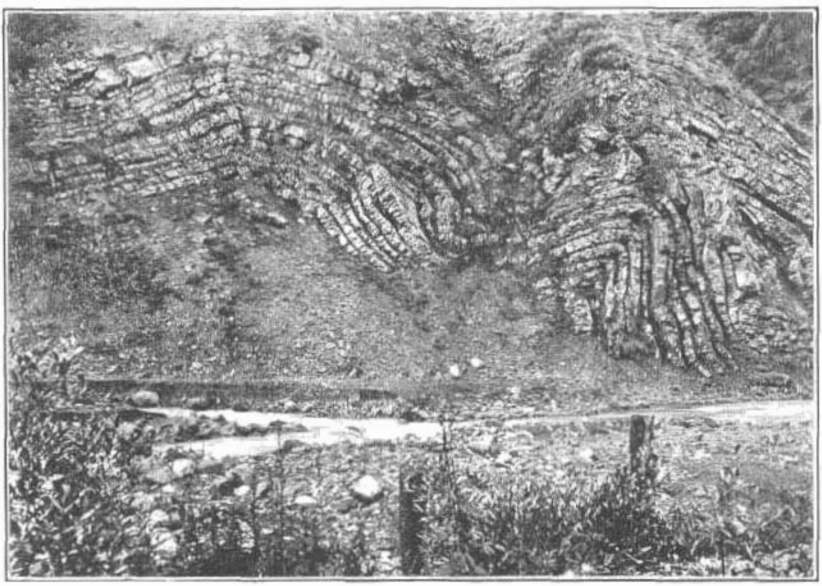
The Nizina district has been described as situated at the southeastern border of the Wrangell Mountains, in the region where this group merges into the Coast Range Mountains to the east and south. The mapped area does not extend far enough north or east to take in any of the larger snow fields or glaciers or to include the highest mountains of the Wrangell group or Coast Range, although peaks of 7,000 or 8,000 feet are shown. To the southeast is the broad lowland formed by the junction of Chitina and Nizina valleys. The map (Pl. II, in pocket) shows as the major features of relief two mountain areas separated by the valley of Nizina River, but other topographic forms are even as striking as these, particularly the steep, straight valley walls, the deep gulches tributary to Young Creek, and the peculiar wormlike rock glaciers.

Three geologic elements are involved in the relief—the high mountain masses, the gravel-covered lowlands, and the gravel benches or terraces. Glacial erosion and the character of the rock formation have



A. TALUS CONES ON EAST SIDE OF McCARTHY CREEK, AT BASE OF LIMESTONE CLIFFS.

See page 19.



B. FOLDED TRIASSIC LIMESTONE AND SHALE BEDS ON SOUTHWEST SIDE OF COPPER CREEK.

See page 28.

been strikingly effective in giving form to the mountains. The work of the ice in straightening and steepening valley walls is conspicuous on Chitistone River and the adjacent part of Nizina River and on the upper part of McCarthy Creek. It is also seen in the numerous cirque valleys in which most of the streams head. McCarthy Creek is a typical example of a glaciated valley in this district. Its upper part is a broad, open, U-shaped valley with gravel floor. Its lower part is a succession of rock canyons with high gravel terraces. These features, except the gravel terraces, are characteristic of every glaciated valley of the region and are probably the result of rapid head valley glacial erosion and the effort of the stream to establish a more advantageous grade after the melting of the ice.

Different kinds of rock were affected in different degrees by the glacial ice and by subsequent erosion. The massive Chitistone limestone forms precipitous cliffs and tall spires, as on Dan Creek, Chitistone and Nizina rivers, McCarthy Creek, and at Bonanza mine. The greenstone slopes are not so steep and are more uniform in surface contour; they rarely form perpendicular walls such as are common in the limestone exposures. The shales give smooth, rounded outlines where they have undergone glacial erosion and sharp, jagged peaks and ridges with steep, bare slopes where they have been subjected to attack by weather alone. These two features are seen in the shale area south of Dan Creek. Between Dan Creek and White Gulch the shale mountains are characterized by angular outlines and bare slopes, but south of Chititu Creek the same shales were overridden by the ice streams from Chitina Valley and present smooth, rounded contours. This feature, however, has been modified by intense postglacial erosion, with the production of such topographic forms as Blei Gulch and the deep gashes cut by tributaries of Young Creek. A different topographic form, dependent on the structure of the upper shale formation, is the flat top of the ridge on the west side of Nizina River directly opposite the mouth of the Chitistone. It is due to the almost horizontal position of the sandstone beds that form the base of the Kennicott in this locality.

Talus deposits cover the lowest mountain slopes and reach their greatest development at the bases of large porphyry exposures and limestone cliffs. In this connection it should be said that the occurrence of a small proportion of porphyry in talus slopes and rock glaciers is usually sufficient to obscure other kinds of rock. Talus fans of noticeable symmetry have been built up below gulches in the limestone formation east of McCarthy Creek (Pl. IV, *A*) and north of Chitistone River. The peculiar detrital accumulations here called rock glaciers are confined to the high mountainous parts of the district but are widely distributed in the mapped area. They are described in the discussion of Quaternary deposits.

The second important element in the relief of the district is the gravel-covered valley lowland areas. Their distribution is readily seen on the map. They represent the accumulated deposits of present glacial erosion and the reworked deposits of former glaciation, together with the contributions of present stream erosion. With the older bench gravels they occupy fully one-third of the mapped area. The bench gravels, which are of glaciofluvial origin, are most conspicuous about the mouth of Dan Creek, the lower parts of Chititu and Young creeks, and on McCarthy Creek, but are present in other places also.

DRAINAGE.

Nearly all the larger streams of the Nizina district originating within the mountain area head in glaciers, and those that do not thus head nevertheless receive much of their water from melting snow banks throughout all or part of the year. All the streams are swift and subject to rapid variations in quantity of water flowing in them. Nizina River falls 600 feet in 19 miles within the mapped area, or at the rate of 31.5 feet per mile. McCarthy Creek has a grade of 100 feet per mile and Chititu Creek 180 feet per mile in their lower courses.

In contrast with the well-drained mountain areas, the lowlands are swampy and dotted with numerous ponds and lakes. They are covered with an inferior growth of spruce and with moss that acts like a sponge to hold water and prevent its rapid run-off. The surplus water from the lakes is carried away in sluggish clear-water streams. These features are characteristic of the southwest part of the mapped area. Trails in such country are often almost impassable for horses in summer, and for that reason they keep to the gravel bars or the ridges.

DESCRIPTIVE GEOLOGY.

STRATIGRAPHY.

SEDIMENTARY ROCKS.

ROCK TYPES.

It has already been stated that the Nikolai greenstone is the oldest rock formation exposed in the Nizina district and that it is conformably overlain by the Chitistone limestone and a shale formation (McCarthy shale), both of which are of Triassic age. It was further stated that a great thickness of shale of Jurassic age—the Kennicott formation—rests unconformably upon the upturned edges of the greenstone, limestone, and shale; that these formations, particularly the Kennicott, were intruded by light-colored porphyritic igneous rocks; and that the most recent deposits of the district are unconsolidated gravels of Quaternary age.

The Nikolai greenstone, because of its relation to the Chitistone limestone, its importance as a geologic formation, and its structure, might fittingly be described in connection with the sedimentary formations. Inasmuch, however, as it is of igneous origin, its description will be taken up later in its proper place in the account of the igneous rocks.

TRIASSIC SYSTEM.

CHITISTONE LIMESTONE.

CHARACTER OF THE FORMATION.

The name Chitistone was applied by Rohn to the great Triassic limestone of the Nizina district because he found the limestone best developed along the Nizina in the vicinity of the mouth of Chitistone River. This name was later adopted by Schrader and Spencer and has since come into general use. The Chitistone limestone is a conspicuous formation occurring all along the south flanks of the Wrangell Mountains from Kotsina River to Dan Creek and probably extending into the valley of the upper Chitina. In the Nizina district the lower part of the Chitistone formation is made up of thick, massive beds of a dark-gray or bluish-gray color but weathering to a lighter gray on the surface. The upper part, on the other hand, is made up of thinner beds, and this thinness increases toward the top. A slight difference in chemical composition between the upper and the lower parts of the Chitistone limestone is indicated by the brownish-yellow weathering of the upper part. Changing conditions of sedimentation are indicated, too, in a more noticeable way by the appearance of thin shale beds at the top of the formation. This limestone is the oldest of the sedimentary formations exposed within the mapped area and lies on the Nikolai greenstone conformably, exactly as if both were sedimentary formations deposited in the same sea and the limestone had been laid down on the greenstone before any movement or disturbance had taken place in the greenstone. This conformable relation holds true wherever the contact has been examined, although in many places it is found that there has been movement of the two formations along this contact surface. In several places a bed of red and green shale with a maximum thickness of about 5 feet was found to intervene between the limestone and the greenstone, but it is not known whether the shale is widely distributed or not, since the limestone-greenstone contact is nearly everywhere covered with talus. The shale is present in the vicinity of Bonanza mine and on Kennicott Glacier.

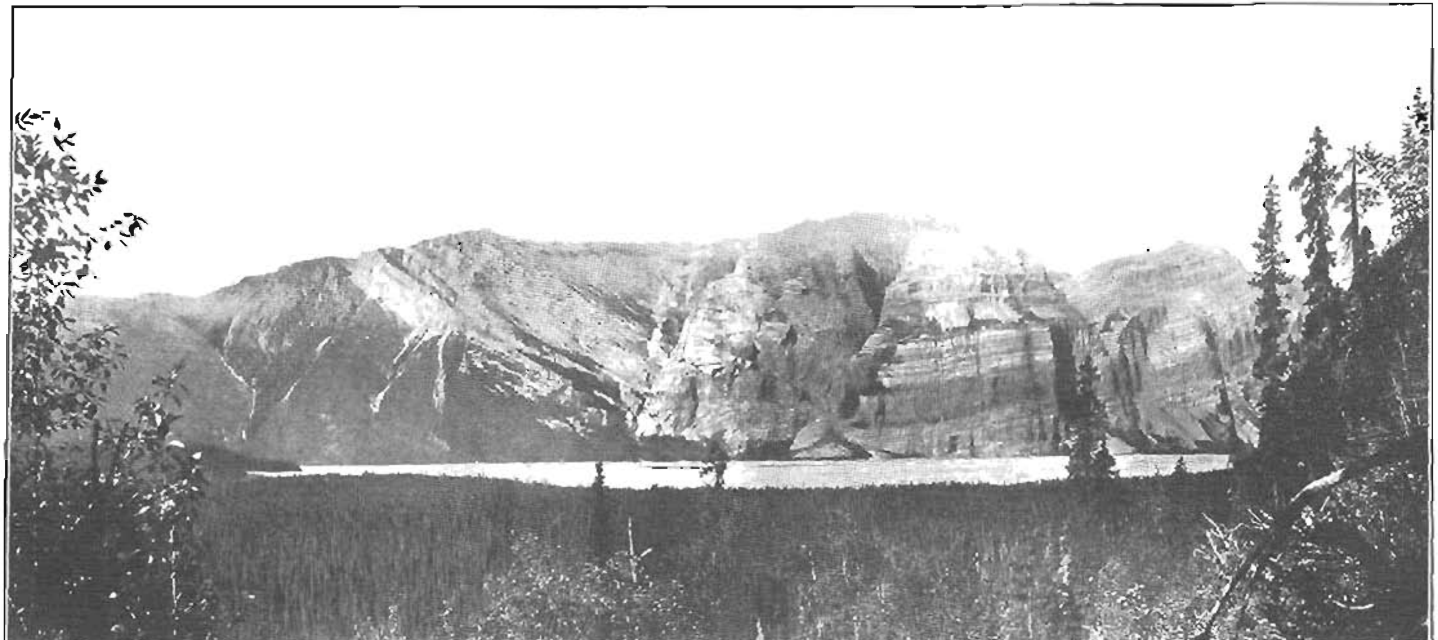
Excellent sections of the Chitistone limestone are seen on the west side of Nizina River, opposite the mouth of Chitistone River, and on McCarthy Creek. On McCarthy Creek the lower part of the formation, which dips about 30° NE., consists of massive beds of bluish-gray limestone, making up approximately three-fifths of the total thickness. Above this lower massive portion is a succession of more thinly bedded limestone strata weathering a rusty-yellow color and making up the remaining two-fifths of the formation. The thickness of individual beds decreases from the base toward the top, as has been stated, and near the top thin beds of black shale make their appearance. Then comes an indefinite thickness, approximately 300 feet, of thin-bedded limestone and shale overlain in turn by a great thickness of black shale, which Rohn called the McCarthy Creek shale.[a] It is thus seen that there is a transition from the bedded limestones below through interbedded thin limestones and shales to shale above, and it is readily understood that difficulty arises in choosing a definite dividing plane between these two formations.

The section on Nizina River shows the same features as that on McCarthy Creek, but here the whole syncline is exposed, revealing the steep northward dip on the south, the horizontal bedding in the middle, and the gentle southward dip on the north. The bedding features are well shown in the center of the syncline for the whole succession from base to overlying shales. (See Pl. V.)

DISTRIBUTION.

The Chitistone limestone occupies a narrow band along the northeastern edge of the mapped area, extending southeastward from Kennicott Glacier (at the northern limit of the area) to the head of Copper Creek. The dip of the limestone along its southern boundary is to the northeast and decreases from approximately 30° in the vicinity of Kennicott Glacier and McCarthy Creek to only a few degrees on Dan and Copper creeks. It results from this that the width of the limestone belt is much less at the glacier and on McCarthy Creek than on Dan Creek. The limestone belt has a width of slightly more than 1 mile on the ridge between McCarthy Creek and East Fork, which is probably less than its width at any place between McCarthy Creek and Kennicott Glacier. East of Nizina River the limestone caps the mountains between Dan Creek and Chitistone River in the form of a broad, shallow syncline fully 5 miles wide. The continuity of limestone exposures is interrupted in many places by valley gravel and talus deposits, but aside from separate limestone areas produced in this way there are a number of small detached areas whose separation from the principal limestone masses represented on the map is due to other causes. Such an area is seen at the head of Nikolai Creek and owes its isolation to the fact that the overlying Kennicott formation has been only partly eroded. If all of the conglomerate and sandstone of the Kennicott

[a] Rohn, Oscar, A reconnaissance of the Chitina River and the Skolai Mountains, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 426.



LIMESTONE WALL ON WEST SIDE OF NIZINA RIVER NEAR MOUTH OF CHITISTONE RIVER.

The limestone overlies the Nikolai greenstone on the left. See page 22.

were removed, the small limestone area would be found to be part of the larger area to the east. Another isolated area lies south of Dan Creek, but in this case the limestone was separated from the main limestone mass to the north and reached its present position through faulting.

THICKNESS.

The two localities on Nizina River and McCarthy Creek afford favorable opportunities for measuring the thickness of the Chitistone limestone, since in both places the whole formation is present. One element of uncertainty presents itself, however—the difficulty of choosing the somewhat arbitrary plane to separate the limestone from the overlying shales; yet, since the intervening thin-bedded shale-limestone succession is probably less than 300 feet thick, the error in measurement, and the results are the same as on Nizina River. A 5 per cent, as will be seen later.

The base of the limestone in the central part of the syncline on Nizina River is hidden by river gravels, but since the curve of the beds is small and regular and greenstone is exposed along the base of the cliffs only a short distance north and south of the axis of the syncline, it is evident that almost the complete section of the limestone is shown in one vertical column. This section gives a thickness of 3,000 feet for the Chitistone limestone in its type locality. The McCarthy Creek section gives an almost equally good chance for measurement, and the results are the same as on Nizina River. A section north of Chitistone River gives a greater thickness than 3,000 feet, but as in this locality the limestone has been folded and faulted it is believed that the figures there are less reliable than those first given.

Exposures of Chitistone limestone extend westward to Kotsina River, less than 15 miles from Copper River, but the thickness is much less than in the Nizina district and in places is not more than 200 or 300 feet. No evidence has been collected to show that the limestone becomes progressively thinner from the east toward the west in Chitina Valley, and, although that may be the case, the decreased thickness in the valleys of Kotsina River and Elliott Creek may be due to erosion before deposition of the Kennicott formation took place.

AGE.

The age of the Chitistone limestone was long in doubt but is now known to be Upper Triassic. This age determination is based on fossil collections made in 1907 at a number of localities along the limestone area from Kotsina River to the Chitistone and on larger collections made in the Nizina district in 1909. All the collections were submitted to T. W. Stanton for determination and the forms present are contained in the following lists. These lists include, however, only the species collected within the area of the Nizina special map. The numbers given the specimens are the catalogue numbers in the National Museum. Concerning the collection of 1907 Dr. Stanton says in part:

The collection is small and fragmentary, but it has proved sufficient to show quite conclusively that the beds in question are of Triassic age. The ammonites, especially, are all characteristic Triassic types, and the few brachiopods obtained are also Mesozoic. There is no indication of Paleozoic fossils in any part of the section represented. * * *

The following lists give the form recognized from each locality. In most cases specific identifications have not been possible, but this does not lessen the accuracy of the age determination:

Bonanza mine and Bonanza Creek:
- 4808; Nos. 9, 14 to 19, 21, 22—
  - Undetermined corals.
  - Terebratula sp.
  - Spiriferina sp.
  - Hinnites? sp.
  - Pseudomonotis subcircularis (Gabb)?

Jumbo Creek, near the Bonanza mine:
- 4809; Nos. 10 to 13, 20—
  - Pentacrinus sp.
  - Terebratula sp.
  - Avicula? sp.
  - Arcestes? sp.

  The last two named are certainly Triassic types of ammonites and probably belong to the genera to which they are provisionally assigned.

South side of Chitistone River:
- 4810: Nos. 23, 24—
  - Spiriferina? sp.
  - Halobia sp.
  - Arcestes? sp.
  - Tropites? sp.

  The last two are Triassic ammonites provisionally identified from imperfect specimens.

The list of fossils collected in 1909 is here arranged by localities. Dr. Stanton says of them:

The fossils from the Chitistone confirm the recent determinations of that horizon and definitely prove that it is of Triassic age.

Jumbo Creek:
- 6300—
  - Base of Chitistone limestone corals? Too obscure for identification.

McCarthy Creek:
- 6330—
  - Terebratula sp. Probably Triassic.

Nikolai Creek:
- 6303—
  - Halobia sp.; related to H. superba Mojsisovics.
  - Undetermined Pelecypod.
- 6306—
  - Juvavites? sp.
  - Arcestes sp.

Nikolai Creek—Continued.

6312—

Pseudomonotis subcircularis (Gabb).
Arcestes sp.
Juvavites? 2 sp.
Orthoceras sp.

Chitistone River:

6319—

Tropites sp.
(Lower part of Chitistone limestone.)

6320—

Halobia superba.
Arcestes.

6333—

Halobia superba Mojsisovics?
Arcestes sp.

Copper Creek:

6321—

Halobia superba Mojsisovics?

When Schrader and Spencer studied the geology of the Chitina Valley in 1900 they found no fossils in the Chitistone limestone and were unable to give conclusive evidence concerning the age of the limestone. They, however, correlated it with the massive Carboniferous limestone at the head of White River, first described by Hayes[a] and later by Brooks.[b]

This limestone is exposed on the north side of Skolai Creek, one of the eastern tributaries of Nizina River, and is conspicuous in Skolai Pass, between the heads of Skolai Creek and White River. The correlation of limestones so similar in appearance and so near to each other seemed to have much in its favor, but better opportunities for study have proved it to be incorrect.

Although the Chitistone limestone can not be correlated with the limestone on White River, it is known that limestone similar in appearance and of the same age as the Chitistone limestone is present on the north side of the Wrangell Mountains, in the depression between them and the Nutzotin Mountains. There is, however, no such development of Triassic limestone there as is seen in the Chitina Valley, and the known exposures are confined to one small area.

A table of correlations for the Mesozoic sedimentary rocks of Alaska is here given, from which it appears that Triassic rocks, so far as they are known at present, are confined to the region south of the Alaska Range. Aside from the Chitina region, Triassic rocks probably have their greatest development in the Cook Inlet region, where they occur principally in the form of cherts with a small proportion of shale and limestone beds.

[a] Hayes, C. Willard, An expedition through the Yukon district: Nat. Geog. Mag., vol. 4, 1892, p. 140.

[b] Brooks, Alfred H., A reconnaissance from Pyramid Harbor to Eagle City, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 359.

Correlation of the Mesozoic sedimentary rocks of Alaska.

		Nizina district (Moffit and Capps, 1909).	Nabesna-White River district (Moffit and Knopf, 1908[a]).	Talkeetna and Matanuska district (Paige and Knopf, 1906[b]).	Cook Inlet and Alaska Peninsula (Stanton and Martin, 1904[c]).	Alaska Range (Brooks, 1902[d]).	Southeastern Alaska (Wright and Wright, 1908[e]).	Yukon Basin (Brooks and Kindle, 1908[f]).	Northern Alaska (F. C. Schrader, 1901[g])
Cretaceous.	Upper				Marine and nonmarine shales and sandstones, conglomerates, coal.			Conglomerates, sandstone, slate, and shale, cut by granite.	Bergman series (?) Nanushuk series. Sandstones with some conglomerate, slate, and lignite.
					Unconformity			Unconformity	Unconformity
	Lower.			Limestone.			Shale, conglomerate limestone, graywacke and slate overlying andesitic lavas, tuffs, breccia, conglomerate, and sandstone, which in turn rest on granite intrusives.	Siliceous slate and quartzites, with some tuff and a little limestone, cut by basic dikes.	Anaktuvuk series and Koyukuk series. Feldspathic sandstones and some conglomerate. Impure limestone, sandstone, slate, and igneous rocks.
								Unconformity	Unconformity
Jurassic.	Upper.	Kennicott formation. Conglomerate shale, sandstone.	Banded slates, graywackes, and conglomerate, with some limestone and sandstone.	Shales, sandstones, conglomerates, tuff, and arkose, with coal.	Naknek formation. Conglomerate, arkose, sandstone, and shale, with interstratified andesite flows.				Corwin series. Gray sandstone, limestone and shale, quartzite, and some coal.
		Unconformity	Unconformity	Unconformity					Unconformity
	Middle.			Shales, sandstone, and conglomerate, with coal. Andesitic greenstone, tuffs, agglomerates and breccias, rhyolites, dacites, and tuffs.	Enochkin formation. Shales and sandstones, with some conglomerate beds.	Tordrillo group. Compact feldspathic sandstones and grits, slate, and some limestone.			

				Unconformity	Unconformity	Unconformity			
	Lower.				Tuffs and sandstones.				
					Unconformity				
Triassic.	Upper.	McCarthy shale, Chitistone limestone.	Limestone.		Thin bedded cherts, limestones, and shales usually much contorted and with many intrusive masses. Base not seen.	Skwentna group, age undetermined. Igneous rocks, with some slates and limestones.	Argillaceous limestones and calcareous sandstones.	Limestones and slates.	
						Unconformity			

[a] Moffit, Fred H., and Knopf, Adolph, Mineral resources of the Nabesna-White district, Alaska: Bull. U. S. Geol. Survey No. 417, 1910, p. 16.
[b] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance of the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, p. 10.
[c] Stanton, T. W., and Martin, G. C., Mesozoic section on Cook Inlet and Alaska Peninsula: Bull. Geol. Soc. America, vol. 16, 1905, p. 410.
[d] Brooks, Alfred H., The Mount McKinley region, Alaska: Prof. Paper U. S. Geol. Survey No. 70, 1911, p. 591.
[e] Wright, F. E., and Wright, C. W., The Ketchikan and Wrangell mining districts, Alaska: Bull. U. S. Geol. Survey No. 347, 1908, p. 34.
[f] Brooks, Alfred H., and Kindle, E. M., Paleozoic and associated rocks of the upper Yukon, Alaska: Bull. Geol. Soc. America, vol. 19, 1908, p. 263.
[g] Schrader, F. C., A reconnaissance of northern Alaska: Prof. Paper U. S. Geol. Survey No. 20, 1904, p. 53.

McCARTHY SHALE.

CHARACTER OF THE FORMATION.

The term McCarthy Creek shale was used by Rohn to designate the black shales immediately overlying the Chitistone limestone, and the formation was described by him as "a series of soft, black, highly fissile shales and slates."[a]

The formation as it is exposed in the Nizina district is essentially a shale formation, although at its base are numerous thin limestone beds forming part of the transition zone at the top of the Chitistone limestone or the base of the shale. Thin beds of limestone are found interstratified with the shales wherever they are exposed within the mapped area, but are not abundant and form only a small proportion of the whole. The top of the McCarthy shale has not been recognized. Bedding is easily distinguished in most places either by the presence of the thin limestones or of thin limy shale beds with surfaces highly colored by weathering. Some of the smooth bare hilltops about the eastern tributaries of East Fork are marked with exceedingly intricate patterns produced by the colored beds, for the McCarthy shale is found to be intensely folded wherever it has been examined, and if the folds are cut by planes or curved surfaces making slight angles with their axes the patterns appear.

The folding in the McCarthy shale strongly contrasts with both that of the Chitistone limestone and that of the Kennicott formation. Pronounced folding took place in the upper thin-bedded part of the limestone in a few localities. It begins to be conspicuous in the transition beds at the base of the shale (see Pl. IV, *B*, p. 18) but was never found in the massive beds at the base of the limestone. The limestone beds were more able than the shale to withstand the pressure that tended to deform them, and that ability increased as the thickness of the beds increased. Another factor of strength lay in the massive flows of the Nikolai greenstone, which lent its support to the heavy beds of the limestone in resisting deformation.

DISTRIBUTION.

The principal area of McCarthy shale represented on the geologic map (Pl. III, in pocket) lies between McCarthy Creek and Nizina River, at the north edge of the sheet. This, according to Rohn, is the south edge of a succession of shales extending north in the McCarthy Creek valley for a distance of 6 or 8 miles and constituting the type locality for the formation. This is not only the largest area of the shales examined but it also shows a greater thickness than any other area, for it suffered less from erosion before the Kennicott formation was deposited.

[a] Rohn, Oscar, A reconnaissance of the Chitina River and the Skolai Mountains, Alaska: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, p. 426.

The McCarthy shale and the shale-limestone transition zone below it form the base of the mountains south of Copper Creek. The formation is separated from the overlying Kennicott formation by a distinct unconformity, but the black shales of the two formations are so similar in appearance that they were not distinguished until the detailed work of 1909 was undertaken. Only the base of the McCarthy shale is exposed on Copper Creek. The upper part was removed by erosion before deposition of the Kennicott began. A smaller area of the Triassic shale forms the mountain top north of Texas Creek, and the formation is present in other places overlying the limestone north of Dan Creek but does not fall within the boundaries of the mapped area.

THICKNESS.

Accurate measurements of the thickness of the McCarthy shale were not obtained, because it is probable that only a part of the total thickness is exposed within the mapped area. It is possible, moreover, that the complete original section is no longer represented in this district, for a long erosion interval intervened between the deposition of the Triassic shales and the Jurassic shales. During this interval much of the Triassic sedimentary formations and of the Nikolai greenstone was removed. Another factor of uncertainty besides the amount of the shales that have been removed by erosion is the thickening and reduplication of beds that arise from folding and faulting. It is probable, however, that the McCarthy shale has a thickness nearly as great as the Chitistone limestone; possibly it is greater.

A thickness of about 1,500 feet of Triassic shale overlies the limestone on the west side of Nizina River. The shales near the center of the broad syncline in this locality have a horizontal position and are probably less distorted by folding than they are to the northwest. This measurement is considered the minimum and probably much less than the true thickness, for some of the shale has certainly been removed by erosion.

The mountains about the head of the East Fork of McCarthy Creek are made up of the black Triassic shales. They reach an altitude of 6,960 feet above sea level or 3,000 feet above the limestone shale boundary at the creek on the southwest. The shales are much folded about the upper part of the East Fork valley, and measurements are consequently uncertain, but it is probable that the thickness of the formation is at least 2,500 feet in this vicinity. No measurements of value were obtained in the Copper Creek section, for, as previously stated, only a part of the formation is present there.

It is evident from what has been said that the total thickness of Triassic sediments in the Nizina district is great and that it is probably not less than 6,000 feet. One-half of this figure represents a limestone whose thickness can be stated with a considerable degree of accuracy; the remainder represents a great shale formation whose thickness is stated only approximately.

AGE.

The McCarthy shale is of Upper Triassic age. Some of the beds are abundantly fossiliferous, especially those near the base of the formation and in the transition zone below, and fossils can usually be found in the higher parts of the formation if search is made for them. Shells of *Pseudomonotis subcircularis* (Gabb) are so plentiful in some of the shale beds between the thin limestones that the rock can not be broken without showing them; they appear, however, to be almost the only forms represented.

A list of fossil localities follows; the determinations are by T. W. Stanton.

McCarthy Creek:
- 6314—
  - Pseudomonotis subcircularis (Gabb).

Nikolai Creek:
- 6311—
  - Two or more undetermined ammonite genera represented by fragmentary specimens.

Dan Creek:
- 6317—
  - Pseudomonotis subcircularis (Gabb).

Copper Creek (two localities):
- 6323—
  - Pseudomonotis subcircularis (Gabb).
- 6335—
  - Pseudomonotis subcircularis (Gabb).

Areas of Triassic shale are scattered along the south slope of the Wrangell Mountains as far west as the Kuskulana and probably as far as the Kotsina also, but in the earlier work in this region the Triassic shales and the black Jurassic shales were not separated because the presence of an immense thickness of Jurassic shales in this valley was not known at that time. It is now certain that a considerable part of the shale areas of Chitina Valley formerly considered to be Triassic are in reality of Jurassic age.

No Triassic shale corresponding in thickness or other characters to the McCarthy shale is known in Alaska. Other regions of Triassic sediments of similar age have been pointed out (see correlation table, pp. 26–27), but the conditions under which they were deposited were different from those in the Nizina district, and although they may be in part contemporaneous the resulting formations are distinct.

JURASSIC SYSTEM.

KENNICOTT FORMATION.

CHARACTER OF THE FORMATION.

The name Kennicott was adopted by Rohn to designate the conglomerate and sandstone succession which he found resting unconformably on the Triassic shales of McCarthy Creek and correlated on fossil evidence with the light-colored arkoses, shales, and limestones between Lachina River and Kennicott Glacier. Rohn did not recognize the black shale south of Nikolai Creek as part of his Kennicott formation, but within the district under consideration the black shale is far more important in amount than the basal conglomerate and sandstone members.

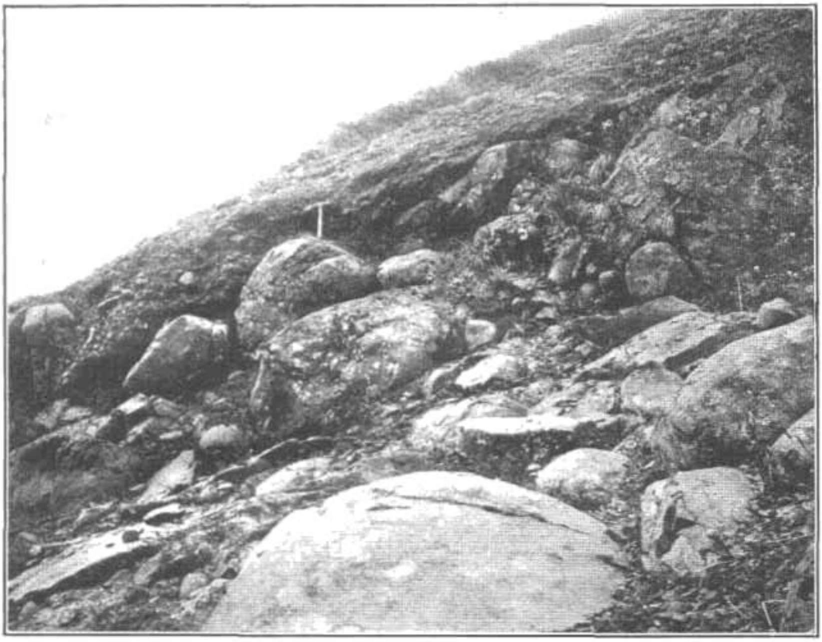
The Kennicott formation as the term is here used consists largely of black shale, but it includes conglomerate, grit, sandstone, and impure limestone members and is intruded by great masses of light-colored porphyritic rock. It is the youngest of the consolidated sedimentary deposits represented on the geologic map (Pl. III, in pocket) and is more widely distributed within the mapped area than any of the formations previously described. One of the characteristics of the Kennicott is its variation in appearance and composition at different localities. This statement is more applicable to its basal than to its upper part and refers to features that resulted from changing shore conditions of sedimentation. These differences will be brought out by a description of the Jurassic rocks northwest of Nizina River, where the basal part is better represented, and southeast of Nizina River, where the middle and upper parts are better represented.

FIGURE 2.—Columnar section of the basal part of the Kennicott formation exposed on Nikolai Creek.

The Kennicott formation where it is exposed about the head of Nikolai Creek may be subdivided into three members as follows: A basal member made up of conglomerate and sandstone; a second member consisting chiefly of light-gray, yellow-weathering shale; and an upper member of dark-gray or black shale interstratified with occasional beds of impure limestone or hard calcareous shale (fig. 2). The basal member shows notable differences in lithologic character and thickness as it is followed from one outcrop to another.

These differences, except in thickness, are dependent in large measure on the kind of rock immediately underlying the Kennicott. In nearly all places the lowest beds of the formation consist of conglomerate, but this conglomerate presents a different appearance in almost every exposure, for there is nearly every gradation between an even-grained grit whose well-worn pebbles are of uniform size and no larger than grains of wheat to a coarse agglomerate with blocks and bowlders up to 8 or 10 feet in diameter (Pl. VI, *A*). Such coarse material has probably traveled but a short distance from its source and may represent a shore-line cliff. It is not a constant feature of the basal Kennicott and its exposures are not extensive, for the very large bowlders are found in only a few localities. In many places it was noticed that most of the pebbles in the conglomerate are of the same material as the older beds on which the conglomerate rests—that is, where conglomerate overlies greenstone most of the pebbles are greenstone and where it rests on the Triassic shale most of the pebbles are shale. Limestone pebbles are not so numerous as pebbles of greenstone and shale, yet conglomerate of this formation containing a large proportion of rounded limestone fragments is found in other parts of the Chitina Valley. Some of the conglomerate contains a considerable number of diorite and porphyry pebbles, but it was not found in place in the vicinity of Nikolai Creek, where the basal conglomerate of the Kennicott is best developed within the area mapped. Nearly all of the fragments are well rounded and waterworn, and it is only in the very coarse conglomerate that angular outlines are noticeable. Even in such places the edges and corners of the blocks are usually worn away.

The filling between pebbles is finely ground material from the same source as the pebbles and is for the most part a greenish sandstone or graywacke. The average size of fragments composing the basal member of the formation decreases rapidly as distance from the base increases, until the conglomerate gives way to sandstone. In most localities about Nikolai Creek where exposures occur it is found that the upper half or three-fourths of the basal member consists of fine greenish sandstone or graywacke containing little quartz and seemingly derived largely from the Triassic shale and the greenstone. This upper part shows far less variation in character than the conglomerate, although in the base thin beds of graywacke alternate with thin beds of conglomerate. There are places where the fine conglomerate and graywacke contain considerable lime and become practically an impure limestone, but such beds are not persistent. Some of them consist in part of broken shells, yet it is difficult to find determinable fossils among them and still more difficult to secure the fossils when found, since they are in most cases partly decomposed and fragile.



A. BOWLDERS IN CONGLOMERATE AT BASE OF KENNICOTT FORMATION ON SOUTH BRANCH OF NIKOLAI CREEK.

See page 32

B. SANDSTONE OF KENNICOTT FORMATION ON RIDGE SOUTH OF NIKOLAI MINE.

See page 33.

This lowest conglomerate-sandstone member of the Kennicott formation on Nikolai Creek has a thickness ranging from 25 to 125 feet, the greater part of which is graywacke, the remainder conglomerate or grit. In a few places the basal member appears to be entirely absent, although because of faulting and talus slopes its seeming absence may be explained in other ways. Furthermore, its persistence as a whole in many other places in spite of rapid changes in character and of variation in thickness makes it probable that if it is not seen in a particular locality the failure to find it is due to one of the causes mentioned.

The middle member of the formation on Nikolai Creek shows far less variation in character than the lower one, but it does not appear so conspicuously in other parts of the Nizina region. It consists of shale and shaly sandstone, but shale predominates. The sandy phases are more or less local, and the best exposures are on the ridge south of Nikolai mine (Pl. VI, *B*). A freshly broken surface of the shale shows a fine-grained rock of light color, but both shale and sandstone weather a bright yellow that makes them conspicuous wherever they are exposed. Both shale and sandstone break down into thin fragments under the influence of the weather, and the débris from their ledges give rise to prominent talus slopes. Occasionally fossils are found in the sandstone, and rarely a shell is seen in the shale, but fossils are not abundant and it requires some search to find any of value. The thickness of the yellow-weathering shales is as great as 500 feet in the mountain between Nikolai Creek and the East Fork of McCarthy Creek. At the head of Nikolai Creek 375 feet of yellow-weathering shale overlies the conglomerate, but some of the shale has been eroded away.

The highest member of the Kennicott in the Nikolai Creek vicinity consists of black shale, with interstratified hard, impure limestone and calcareous shale beds ranging in thickness from 1 inch to 2 feet. The hard beds form only a small proportion of the total thickness, probably less than one-tenth, but although jointed and broken they stand out in relief from the softer, crumbling black shales and form a conspicuous part of the whole. This black shale resembles closely the black shales of the Triassic. The hard beds assume a rusty-yellowish color on weathering, just as in the Triassic shales, and there seems to be no way, except by their stratigraphic position and their fossils, to distinguish them from the older shales. Fossils are fairly plentiful in some beds of this member, especially those in the hard beds, and are in a better state of preservation than those found lower in the formation.

From 125 to 150 feet of these shales are exposed north of Nikolai Creek, but the figures take no account of what has been removed by erosion or what has been caught up into the intruded porphyry.

Locally erosion has destroyed the upper member, leaving the basal and middle members. In some localities both the middle and the upper members have been removed, and without doubt the Kennicott was once present in large areas where no trace of it is now found.

The section of the Kennicott formation exposed on Dan Creek is many times thicker than the section that has been described. The Nikolai section represents a phase of the basal Kennicott that is thought to correspond more fully with the Kennicott observed west of Kennicott Glacier and still farther west in the Chitina Valley than does the Dan Creek section. An excellent exposure of the base of the Kennicott formation was found on Eagle Creek, in the Copper Creek valley. All the upper part of the long ridge separating Eagle Creek from Copper Creek is made up of lower Kennicott beds. They rest on the edges of thin limestone and shale beds that belong to the transition zone between Chitistone limestone and McCarthy shale. The limestone and shale beds have a dip about 20° greater than the overlying Kennicott, and the unconformity is shown in diagrammatic clearness. The basal beds of the Kennicott at this place consist of from 150 to 200 feet of fine conglomerate or grit overlain by sandstone. Black shale overlies the sandstone and forms the top of the ridge extending southeast to the main mountain mass. This basal grit was traced northwest in Copper Creek valley to the vicinity of the limestone area north of Idaho Gulch. It may be regarded as a constant feature of the Kennicott in the Nizina district. In most places it is somewhat fossiliferous. Pyramid Peak, at the head of Copper Creek, appears to be made up entirely of rocks belonging to the Kennicott formation. The lower part is black shale, but the top shows bedding lines that are thought to represent sandstones and impure limestones. Sandy shales and hard sandstones are interstratified with the black shales on Rex Creek, and the tops of the mountains between Rex Creek and White Creek contain a large amount of gray sandstone and impure limestone. Beds of brown-weathering nodular limestone in the shales high up on the slopes of these mountains contain ammonite shells 15 or 18 inches across. These mountains appear to be at the axis of a broad shallow syncline and give good sections of the formation.

A feature of geologic interest is presented by the sandstone dikes that cut the black shales east of Rex Creek. These dikes range in thickness from a fraction of an inch to 5 or 6 inches and cut the shales just as an igneous dike would. They are composed of angular fragments of quartz, feldspar, biotite, calcite, and pyrite mingled with fragments of shale. They are composed of the same material as some of the associated sandstone beds and are numerous in places.

Bedding in the black shales of Blei Gulch, on the south side of Chititu Creek, is shown by lines of small limestone concretions and thin discontinuous calcareous beds. More than 4,500 feet of black shale dipping low to the southwest is exposed in Blei Gulch. Young Creek, south of Chititu Creek, flows in a shallow canyon whose walls are composed of black shale of the Kennicott formation. This shale forms the lower slopes of the ridge south of Young Creek, and it is probable that Kennicott sediments make up most of the ridge. The ridge was not examined in detail owing to lack of time, but a section up the first southern tributary of Young Creek east of Calamity Gulch shows rocks of the Kennicott formation. The section extends up the east branch of this creek. For a distance of nearly three-fourths of a mile from its mouth the creek flows over black shales with occasional limestone beds, all dipping southwest at angles of 30° or less. Thence for nearly a fourth of a mile are rocks that have been crumpled and much faulted. They consist of shales with interbedded calcareous shales and limestone, from which fossils were collected. In many places the strata of this disturbed zone stand on edge, and it is evident that displacements of importance have taken place. A peculiar feature of this locality is seen in the limestone nodules, which occur in beds and reach diameters of 2 or 3 feet. They consist of bluish-gray limestone and show parallel bedding lines crossing them. They were seen at a number of places on Young Creek. South of this faulted zone the creek flows for another three-fourths of a mile over black shales and thin gray and brown sandstones. The shale predominates but the sandstones form an important part of the whole. The dip of these shales and sandstones is steeper than is usual in the Kennicott formation of the Nizina district, ranging from 30° to 50°. A massive conglomerate succeeds the shale and limestone on the south at a point 1,500 feet above Young Creek. The conglomerate is several hundred feet thick and is made up of well-rounded pebbles loosely cemented together, many of which are 5 or 6 inches in diameter. It appears to have been deposited conformably on the underlying shale-sandstone beds, but there is reason to believe that movement has taken place along the contact at this locality. No proof was secured to show that this great conglomerate does not mark an unconformity in the Kennicott formation or between the Kennicott and a succeeding formation, but the relation appears to be one of conformity in other places west of this creek where the contact was examined. Flat-topped or mesa-like hills composed of conglomerate beds dipping low to the south are scattered along the top of this ridge both to the east and to the west of this section. According to Schrader's field notes of 1900, the conglomerate on the west end of the ridge south of Young Creek is interstratified with a few beds of arkose sandstone and probably does not exceed 500 feet in thickness. It contains granite bowlders up to 9 inches in diameter, dark limestone, flint, quartz, gray slate and grit, and green gneissic rock, but

Schrader did not find any pebbles of Nikolai greenstone. The arkose or sandstone underlying the conglomerate was measured by Schrader in a very favorable section, where the dip was low to the south-southeast, and was found to be between 2,000 and 2,500 feet in thickness.

There is no reason to doubt that this succession of shales, limestones, sandstones, and conglomerate found in the ridge south of Young Creek corresponds to the bedded rocks seen in the high mountains at the head of Copper, Rex, and White creeks. It therefore represents the upper part of the Kennicott formation as it is known at present.

The unconformable relation of the Kennicott formation to the older sedimentary rocks and the Nikolai greenstone is plainly seen in both the localities whose sections have been described and is shown in the view (Pl. VII, *A* and *B*) taken at the head of Nikolai Creek. Kennicott sediments there rest on the upturned and truncated beds of the Nikolai greenstone, the Chitistone limestone, and the McCarthy shale. The dip of the younger beds is low in most places, ranging from 10° to 20° W. or SW. On the other hand, the dip of the underlying sediments and the lava flows (Nikolai greenstone) are considerably greater and in a different direction, averaging about 30° or 35° NE.

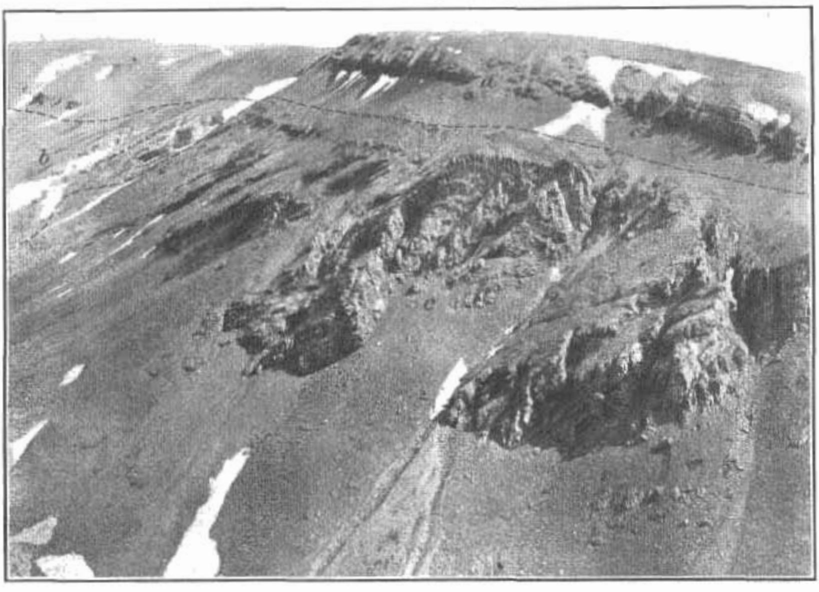
One feature of the Jurassic sediments that is more noticeable on White and Young creeks than in other parts of the district is the rapidity with which they break down under the action of weathering. Such topographic forms as Blei Gulch and the gulches tributary to Young Creek are due to this cause. Blei Gulch in particular shows how readily the shales are attacked and how little they are able to resist the attacks as compared with the greenstone and limestone. The soft shale débris accumulates faster than the water can carry it away and the mouth of the gulch is choked with it.

The Kennicott was deposited on an old submerged land surface. In a broad way this surface on which the Kennicott formation of Nikolai Creek lies was flat, but it is readily seen on examining the contact that there were minor irregularities in it such as are present in any level country. The conglomerate and graywacke beds of the basal Kennicott sag down into hollows of the underlying surface, and at one locality pebbles and sand were seen filling old cracks in the Chitistone limestone.

DISTRIBUTION.

The Kennicott formation occupies probably three-fourths of the total area represented on the geologic map (Pl. III, in pocket), for if a line be drawn from the mouth of National Creek to Pyramid Peak practically all of the consolidated deposits south of it are Kennicott. It forms the high angular mountains between Dan and Chititu

A.



B.

UNCONFORMITY BETWEEN TRIASSIC AND JURASSIC FORMATIONS AT HEAD OF NIKOLAI CREEK.

a, Sandstone and shale of Kennicott formation; *b*, Chitistone limestone; *c*, Nikolai greenstone. The two views placed side by side would form a panorama. See page 36.

creeks and makes up the principal part of Porphyry and Sourdough peaks, although its presence is so obscured by porphyry intrusions in these two last-mentioned mountains that its amount is apt to be underestimated. It doubtless underlies also the gravel deposits of the lowland south of Nizina River.

Without question Jurassic sediments are far more widespread in Chititu Valley than was suspected before the field work of 1909 was undertaken. They extend eastward beyond the Nizina district into the upper valley of the Chitina and westward along the flanks of the Wrangell Mountains, where it is certain that they have not been fully differentiated from the Triassic shales, just as was true in the Nizina district. The separation of Jurassic from Triassic shales will require more detailed field work than has yet been given them.

THICKNESS.

No such favorable section was found for measuring the thickness of the Kennicott formation as that furnished by the walls of Nizina River for measuring the Chitistone limestone, and the figures given are secured from a study of a number of sections at different localities (fig. 3). The total thickness given should be regarded as having only approximate accuracy.

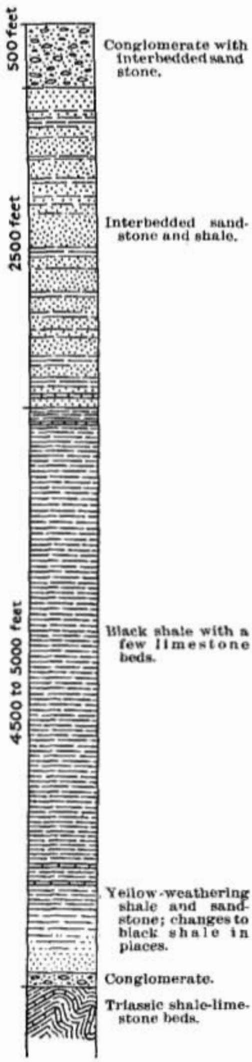


FIGURE 3.—Generalized columnar section of the Jurassic sediments in the Nizina district.

The coarse fragmental beds, including conglomerate and grit at the base of the Kennicott, range in thickness from 25 to 150 or 200 feet. An intermediate figure of 100 to 150 feet is believed to represent a fair estimate for the thickness of these beds throughout the district. It seems proper to include the yellow-weathering shales and sandstones of Nikolai Creek with the black shales, since they are a local feature and contemporaneous in time of deposition with the lower part of the black shale south of Nizina River. On this basis the black shale member at the heads of Copper and Rex creeks has a minimum thickness of not less than 4,500 feet, yet the black shales of Williams Peak south of Dan Creek suggest a considerably greater thickness, possibly as much as 6,000 feet. This measurement includes all beds from the top of the conglomerate and grit to the beginning of the interbedded shale-sandstone succession that forms the tops of the high mountains at the heads of Copper and Rex creeks and the upper part of the ridge south of Dan Creek. The shale-sandstone member has a thickness of about 2,500 feet. If, now, 500 feet, representing the heavy conglomerate of Young Creek, be added to the measurements already given, a minimum thickness of over 7,500 feet is obtained for the Kennicott formation in the Nizina district.

AGE AND CORRELATION.

Fossils have been collected from all parts of the Kennicott formation, but unfortunately the stratigraphic range of the forms is so great that they do not fix its age definitely. It appears most probable that the Kennicott formation was laid down in Upper Jurassic time, but there is a possibility of its being Lower Cretaceous. The probability of its Jurassic age rests in considerable measure on the presence of a species of *Aucella* collected first by Rohn and later by Schrader and Spencer and identified by T. W. Stanton. Schrader and Spencer collected fossils at other localities as well as in the Nizina district, and on the evidence of these fossils the formation was referred to "the doubtful series lying at the top of the Jurassic or at the base of the Cretaceous."[a]

The list of fossils follows.

Inoceramus eximius Eichwald?
Belemnites sp.
Halobia occidentalis Whiteaves?
Rhynchonella sp.
Pecten sp.
Avicula sp.
Aucella pallasi Keyserling?
Lytoceras sp.
Hoplites sp.
Olcostephanus? sp.
Gryphæa sp.
Sagenopteris sp.

Concerning *Inoceramus eximius* Dr. Stanton says:[a]

> This form is represented by a single specimen collected on Chitty Creek. It may be distinct from Eichwald's species originally described from Turkusitun Bay, in Cook Inlet, and referred by him to the Neocomian. Eichwald described three other species—*I. ambiguus*, *I. porrectus*, and *I. lucifer*—all belonging to one section of *Inoceramus* from the same horizon in Alaska. The present shell does not agree perfectly with any of the figures, but it is most nearly like *I. eximius* and probably comes from the same formation. Similar forms occur both in the Jurassic and in the Cretaceous, but the evidence of the other fossils from this part of Alaska favors the reference of the Kennicott formation to the Jurassic.

[a] Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, Alaska: Special publication of the U. S. Geol. Survey, 1901, p. 50.

Of the form referred with a question to *Halobia occidentalis* Dr. Stanton says:

The specimens agree fairly well in sculpture and general appearance with some of the figures of Whiteaves's species from the Liard River and may be identical with it. They are, however, somewhat suggestive of *Hinnites linœnsis*, from the Jurassic(?) of Siberia.

Sagenopteris is a genus which occurs both in the Jurassic and in the Cretaceous, but the species is thought by Prof. Ward, to whom it was shown, to be near a species occurring in the Jurassic of the Pacific coast.

Concerning the general relations of the fossils from the Kennicott formation Dr. Stanton observes:

These fossils are all either Upper Jurassic or Cretaceous, with a suggestion of a somewhat younger age for a few localities. In the present state of knowledge and with these small collections it is not practicable to determine whether they represent one horizon or several. In my opinion, they probably all belong to the Upper Jurassic, though subsequent work may show the contrary. The question is connected with the still unsolved problem of the exact boundary between the Jurassic and the Cretaceous in the *Aucella*-bearing beds of Russia, Siberia, and the Pacific coast region of North America. The *Aucella* occurring in the Copper River district appears to be referable to a Russian Jurassic species, but it is also quite similar to the Cretaceous form in the lower Knoxville beds of California. The few other forms are mostly undescribed species of types that occur both in the Jurassic and in the Lower Cretaceous.

A single fossil collected on Chititu Creek in 1907 was referred to Dr. Stanton and described by him thus:

Chititu Creek:

4811; No. 26—

Perisphinctes, sp. This ammonite is not a typical Perisphinctes, but it is probably of Jurassic age, certainly not older than Jurassic.

The much larger collection made in 1909 was also referred to Dr. Stanton, who says of them: "The fossils from the Kennicott indicate that one fauna ranges throughout the formation and that its age is most probably Jurassic, though the types represented in the collection are not as definite as could be wished for determining between Jurassic and Cretaceous. The entire absence of *Aucella* is noteworthy in view of the fact that that genus has previously been reported from the formation." The list of fossils arranged by localities and with the catalogue numbers of the National Museum follows.

McCarthy Creek:

6301—

Inoceramus sp.

6313—

Lytoceras sp.

Phylloceras sp.

Base of Kennicott.

Nikolai Creek:
6302—
Inoceramus sp.
Base of Kennicott.
6304—
Rhynchonella sp.
Pecten sp.
Base of Kennicott.
6305—
Rhynchonella sp.
Terebratella? sp.
Exogyra sp.
Pecten sp.
Collected near 6304.
6307—
Phylloceras sp.
6308—
Inoceramus sp.
Lower part of Kennicott formation.
6309—
Rhynchonella sp.
Inoceramus sp.
6310—
Rhynchonella sp.
Terebratella? sp.
Base of Kennicott formation.
6331—
Rhynchonella sp.
Terebratella? sp.
Ostrea sp.
Rear base of Kennicott formation.
Sourdough Hill:
6315—
Inoceramus sp.
Dan Creek:
6316—
Inoceramus sp.
6318—
Bowlder in conglomerate of Kennicott formation.
Halobia superba Mojsisovics?
Copper Creek:
6322—
Rhynchonella sp.
Undetermined small Pelecypoda.
Natica sp.
Undetermined ammonite.
Base of Kennicott formation.
Texas Creek:
6334—
Phylloceras? sp.
Rex Creek:
6324—
Irregular echinoid, crushed specimens.
Pecten sp.

Rex Creek—Continued.
6324—Continued.
Terebratula sp.
Ostrea sp.
Anomia sp.
Inoceramus sp.
Nucula sp.
Arca sp.
Undetermined Gastropoda.
Phylloceras sp.
Shark's teeth.
Well up in the Kennicott formation.
6425—
Serpula sp.
Ostrea sp.
Pecten sp.
Arca sp.
Cyprina? sp.
Corbula sp.
Aporrhais sp.
Chemnitzia? sp.
Crioceras? sp.
6426—
Fragment of large ammonite.
Higher in the formation than 6324.
6336—
Undetermined fragmentary ammonite.
White Creek:
6327—
Ostrea sp.
Upper part of Kennicott formation.
6328—
Fragment of large ammonite.
High up in the Kennicott.
Young Creek:
6329—
Cyprina? sp. (fragment).

The absence of *Aucella* from the collections of 1909 raises a question concerning the Kennicott that can not be answered with the data at hand. If, as seems probable, its absence is due merely to the failure to find it, there is no reason to suspect any difference in age of the Kennicott sediments east and west of Kennicott Glacier. If, on the other hand, it does not occur east of Kennicott Glacier, the possibility that the basal Kennicott beds west of the glacier are older or that the sediments of the two localities are not correctly correlated is apparent.

It will be seen from the table of correlation (pp. 26–27) that Jurassic sediments are widespread in Alaska. They are found along the Pacific coast side from southeastern Alaska to the peninsula, and again on the Arctic slope, but are not known in the Yukon Basin.

Attention is directed more particularly to the Nabesna-White district, the Matanuska and Talkeetna district, and the region of Cook Inlet and the Alaska Peninsula.

The Nutzotin Mountains, northeast of the Wrangell group, consist of a great thickness of banded slates, graywackes, and conglomerates associated with limestone and sandstone beds in minor amount. Upper Jurassic fossils were collected from these beds, but the beds are very imperfectly known, and it is highly probable that they include also Triassic or even older beds. They are exposed in the canyon of Chisana River for a distance of 18 miles, and, although they are much folded, it is evident that their thickness is great.

Lower Middle Jurassic and middle and upper Middle Jurassic sediments occupy extensive areas in the region of Matanuska and Talkeetna rivers.[a] The lower Middle Jurassic rocks have a thickness of 2,000 feet, more or less, and consist of shales, sandstone, and conglomerate, with coal, associated with andesitic greenstone, tuffs, agglomerates and breccias, rhyolites, dacites, and tuffs. On these was deposited unconformably more than 2,000 feet of middle and upper Middle Jurassic shales, sandstones, conglomerates, tuff, and arkose, with coal. More than 1,000 feet of this is conglomerate.

The Jurassic rocks of Cook Inlet and the Alaska Peninsula were studied by Stanton and Martin in 1904[b] and again by Martin in the region of Iliamna Bay in 1909. They include rocks of Lower, Middle, and Upper Jurassic age. The deposits referred to the Lower Jurassic consist chiefly of water-laid tuffs, and are found at Seldovia, on the east side of Cook Inlet, and probably on the west side also. The Middle Jurassic sediments, called by Stanton and Martin the Enochkin formation, include shale and sandstone, with a few thin beds of limestone and conglomerate, and reach a thickness of 2,415 feet on the shore of Chinitna Bay. This section does not include the lower part of the Enochkin formation, yet the thickness given represents what is probably the average thickness of the formation. Upper Jurassic sediments succeeded the Enochkin formation. They were first described by Spurr[c] and received their formation name from Naknek Lake. The Naknek formation includes shale, sandstone, conglomerate, arkose, tuff, and andesite. A thickness of 5,137 feet of rocks belonging to this formation was measured by Stanton and Martin on the north shore of Chinitna Bay. Lower, Middle, and Upper Jurassic deposits thus reach a thickness of 7,500 to 8,500 feet in this region.

[a] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, pp. 16 and following.

[b] Stanton, T. W., and Martin, G. C., Mesozoic section on Cook Inlet and Alaska Peninsula: Bull. Geol. Soc. America, vol. 16, 1905, pp. 391–410.

[c] Spurr, J. E., A reconnaissance of southwestern Alaska: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 169–171.

It has been seen from the brief description given that the Jurassic section is more nearly complete as it is traced westward from the Chitina Valley. The evidence is too incomplete to draw definite conclusions, but it appears that about the lower part of Cook Inlet Lower, Middle, and Upper Jurassic sediments are present, that in the Talkeetna and Matanuska district the Lower Jurassic is lacking, and that in the Chitina Valley both Lower and Middle Jurassic are absent. A possible explanation of this condition is that the invasion of the Jurassic sea was from the west and that the successive dropping out of the lower members from the stratigraphic section is evidence of progress in the eastward advance. This explanation, however, is not the only one, for the lower divisions of the Jurassic may yet be found in the Chitina Valley, or they may have been removed by erosion if ever present. In this connection, also, attention may once more be drawn to the fact that the known Jurassic sediments of Alaska are found on its Arctic and Pacific sides. They have not been discovered in the Yukon Basin.

QUATERNARY SYSTEM.

PREGLACIAL CONDITIONS.

So far as known, the region under discussion was elevated above sea level at the end of Eocene time and has ever since remained a land area. During and after the cessation of the mountain-building processes which raised the land to its present elevation stream erosion was active and well-developed drainage systems were formed, the area and distribution of which were perhaps very much as they are to-day. The topography of the land surface and the arrangement of the smaller drainage lines must, however, have been greatly different from those existing at present. The relief was developed by stream erosion, and in a region of such great relief the streams must have occupied narrow V-shaped valleys, with the spurs between the lateral tributary valleys overlapping in such a way as to give the streams a somewhat sinuous course around the points of the interlocking spurs. Furthermore, there must have been a heavy covering of residual soil and rock waste mantling the ridges. Stream erosion was the controlling factor in the development of the topography up to the beginning of Pleistocene time.

PLEISTOCENE ("GLACIAL") EPOCH.

CHARACTER AND EXTENT OF GLACIATION.

A change in climatic conditions inaugurated the Pleistocene epoch, with a lowering of the temperature or an increase in precipitation, or both. Ice began to form in the heads of the more favorably situated valleys, and with the gradual accumulation of ice glacial movement was started. The small glaciers which formed in the heads of a great number of separate valleys moved gradually downward to meet and merge in the main valleys. Three primary glaciers existed within the limits of this district, two of them (in the Kennicott and the Nizina valleys) moving southward and one (in the Chitina Valley) moving westward.

It is possible that the Pleistocene epoch has been represented in these mountains by more than one great ice advance, with interglacial epochs in which the ice diminished greatly in area and may even have disappeared in large part. No direct evidence has been obtained that this was the case in Alaska, as the last great ice advance obliterated all evidence of previous advances. In other mountain regions in the United States and Canada a succession of ice advances has been established, and somewhat similar conditions have probably prevailed in Alaska. The effects of earlier ice invasions may have had an important influence upon the erosion of the deep glacial valleys of this region, but the immediate effects now remaining, such as the distribution of moraines and glacial gravels, are to be ascribed to the action of the last great glaciers which filled these valleys.

As already stated, the dissection of the area in preglacial time had been accomplished by normal stream erosion. Great quantities of soil and rock waste were ready at hand for the glaciers, and these materials were incorporated into the advancing ice tongues and served as abrasives for the glaciers to use in the further grinding out of their beds. As they advanced down their valleys they encountered opposition from the spurs which projected into the valleys, and as the ice was able to override these spurs it was upon them that its erosion was most effective. This selective erosion of projecting bodies of rock was carried on continuously, and the resultant is the broad, U-shaped, troughlike gorge which is recognized as the evidence of severe glacial erosion. Erosion in the valleys, however, was not confined to the removal of overlapping spurs. The rock fragments held in the bottoms of the glaciers and pressed down upon their floors by the weight of several thousand feet of ice formed admirably adapted tools for grinding down the floors and rasping away the walls. It is impossible to estimate with any degree of accuracy the amount of glacial deepening which the trunk valleys have undergone. The difference in elevation between the mouth of a hanging tributary valley and the floor of the main valley below may be considered to offer a fair basis for estimating this deepening, and in many places this discordance is from 1,000 to 1,500 feet. Some such figure may well represent the depth to which glacial scour has lowered the larger valleys.

At the time of the last great period of glaciation the Nizina region was invaded by an ice flood which covered it to such an extent that the surface relief within the area was not more than 4,500 feet as compared with more than 7,700 feet at the present time. Only the high ridges between the principal drainage lines projected above the surface of the ice streams. The land areas were restricted to narrow, angular masses of irregular outline cut into on all sides by the smaller glaciers, which headed back toward the crests of the divides. An attempt has been made (Pl. III, in pocket) to outline the land areas which projected above the glaciers. This outline can not be considered as exact, but it must represent with a fair degree of accuracy the areas which stood up above the ice surface. Of the total area of the Nizina special map (300 square miles) only about 18 square miles remained unglaciated.

The depth at which the ice stood in the different valleys can in favorable places be determined rather closely by the present distribution of glacial moraines and erratic bowlders and by the shapes of the eroded valley walls. Certain mountains, we know, must have stood above the glaciers, because of the angular, rugged character of their summits, which fail to show the effects of the abrasive action of the ice. Other mountains, we know, must have been overridden by the ice, because of their smoothed and rounded outlines and because of the occurrence on their tops of glacial bowlders of rocks which occur in place nowhere in the vicinity of their present resting places. From such evidence it is found that in Nizina Valley, at Sourdough cabins, the top of the glacier must have stood more than 3,000 feet above the present river flat.

CHITINA GLACIER.

The Chitina Valley, which extends from the head of Chitina River near the international boundary in a west-northwest direction to the Copper River basin, is the channel which drained all the ice fields from the south side of the Wrangell Mountains as well as those from the north slope of the Chugach Range. Although only one edge of the Chitina Glacier lay within the area of the Nizina special map, it may not be out of place to give here some idea of the size of this ice tongue as a whole. At its maximum it was about 120 miles long in its own valley, and it joined the Copper River Glacier, the length of which below the junction of the Chitina is not known, although it must have been considerable. The ice field had a width for portions of its course of 20 miles and averaged about 12 miles, so that its total area was not far from 1,500 square miles, exclusive of all tributary glaciers. South of this area it was certainly close to 4,000 feet in thickness and may have been much thicker. On account of its great thickness the ice surmounted the divide between Chitina River and Young Creek and pushed to the northwest, covering the ridge between Young and Chititu creeks, so that the northern boundary of this great ice field was here the high mountain ridge north of White Creek. That it completely covered the high divides south of this ridge is evident not only from the smoothed and subdued slopes of their summits but from the presence on them of scattered bowlders of rocks strange to this immediate vicinity. In Chititu and White creeks there are numerous bowlders of greenstone, although none occurs in place within this drainage basin. Their presence here as well as that of the native copper and silver found in the placer gravels is doubtless due to the transportation of glacial ice, the bowlders in White Gulch having been brought from the east by the Chitina Glacier, and the bowlders in Rex and Chititu creeks either by the same ice tongue or from the north by the Nizina Glacier. Much of the native copper and greenstone of Young Creek was brought in by the Chitina Glacier, although there may be greenstone in place at the head of this creek. There is still a large glacier at the head of Chitina Valley, though little is known of its length or appearance.

NIZINA GLACIER.

The head of the Nizina Basin is still occupied by a great glacier, which now terminates about 11 miles above the mouth of Chitistone River. The valley below, however, shows strongly the erosion of the former glacier which moved down it. Tributary ice tongues entered the valley from both sides north of the area here considered, but within it the large branches all came in from the east. The northernmost and by far the most important branch came down the Chitistone Valley. This stream drains a basin which extends northeast to Skolai Pass and east into a range of high glaciated mountains. That the valley was the outlet for a vigorous glacier is evident from the steep-walled trough through which the stream now flows. The valley floor near the mouth of the canyon is only three-eighths mile wide, but the ice in it once reached a depth of at least 3,500 feet and was able to keep its trough cut down to grade with the floor of the Nizina Valley. Toward the lower end of the Chitistone Valley the tops of the mountains on both the north and the south sides are flat and mesa-like, and, although the valley glacier did not extend up to these mesas, they were occupied by glaciers which must have extended to their edges and cascaded down upon the valley glacier below, so that only a portion of the steep cliffs at the upper limit of the valley walls were free from ice.

Five miles south of the Chitistone a tributary ice tongue fed into the Nizina from Dan Creek. This lobe drained the ice from a much smaller basin than the Chitistone and excavated its valley much less severely. In it the depth of the ice was great, but this was due more to the damming back by the great glacier in the Nizina Valley than to its own supply, and the movement must have been comparatively sluggish. Besides receiving ice from a large number of cirques, some of which are still occupied by small glaciers, this lobe was fed by the ice sheet on the mesa to the north. This ice sheet still exists and covers most of the flat uplands, but now sends ice over its edge at only a few points.

The main valleys of Chititu and Young creeks were invaded by ice from the Chitina Glacier, which spread over the intervening ridges and made a continuous ice sheet from Chititu Creek to the south side of the Chitina Valley. Rex Creek, however, was separated by a high ridge from the Chitina ice and sent down a tributary tongue to join the great ice flood at the junction of the Nizina and Chitina glaciers.

KENNICOTT GLACIER.

The Kennicott Basin is occupied in its upper portion by a glacier which extends within 5 miles of the mouth of Kennicott River. The area of the Nizina special map includes about 10 square miles of the eastern edge of this ice tongue. A line drawn from Kennicott to the point of junction of the two principal branches of the glacier separates the white ice of the east fork from the moraine-covered ice of the lower portion. The west fork, which is the larger, heading on the flanks of Mount Blackburne, shows a banded, ribbon-like surface of lines of white ice alternating with long surface moraines. Below the junction of the two branches the white bands disappear and the glacier presents a chaotic surface of sharp hills and deep, wide-mouthed crevasses, all more or less thickly covered with débris. Part of the drainage from the melting ice runs off as streams, which flank the lower portion of the glacier on either side, but much the greater part of the water emerges from what is known as the "pothole," at the lower end of the glacier. The pothole is the mouth of a subglacial channel, and Kennicott River boils out of this opening as a gigantic spring. In winter the pothole has been known to freeze up, damming back the water until sufficient hydraulic pressure has been developed to break away the ice, when a torrent of water rushes down Kennicott and Nizina rivers, sometimes flooding the ice all the way to Copper River.

The severity of the earlier glaciation in the Kennicott Valley is comparable to that of the Nizina. The ice extended southward to join the great Chitina Glacier, which had already been swelled by the ice from the Nizina. The surface of the glacier at Kennicott then stood about 3,000 feet higher than it does to-day, and the severity of its erosion is shown by the straight lines of the contours along the mountain sides and by the complete absence of projecting spurs.

The Kennicott Glacier had within this area one important tributary, which occupied the valley of McCarthy Creek. Its course, like that of the Kennicott and Nizina glaciers, was from north to south, and its erosion was sufficient to reduce its valley to a straight, U-shaped trough. Within the area of this map all the important tributaries to McCarthy Creek Glacier came in from the east, especially from the valleys of Nikolai Creek and East Fork. At one time the ice surface stood 1,000 feet above the divide at the head of South Fork of Nikolai Creek, and it is probable that some of the ice from the Nizina Glacier moved westward over this col and then down the McCarthy Creek valley. Below Sourdough Peak the Kennicott, McCarthy, and Nizina glaciers all joined the great Chitina ice stream and moved northwestward down the Chitina Valley.

In the preceding paragraphs the attempt has been made to describe the glaciers of the region at the time of their greatest development. The individual ice lobes and their interrelations would have been different at lesser stages of development. The arrows shown on the map (Pl. III, in pocket) represent the directions of ice movement in the different parts of the area.

RETREAT OF THE ICE.

In the earlier stages of glaciation of the region the ice no doubt built up lateral and terminal moraines, but further advances destroyed or obliterated all traces of the earlier deposits. It is only those deposits that were laid down at the time of or subsequent to the maximum advance of the ice that have been preserved, and in many places even this material has been removed by stream cutting or been covered with stream deposits. There are left only a few areas of distinctive terminal moraine, having the characteristic hummock and kettle topography. Some such moraine still exists west of the lower portion of Young Creek, and some east of lower Chititu Creek, with occasional more recent patches like that on Texas Creek near the head of Copper Creek. These areas often contain lakes which occupy undrained depressions in the glacial deposits. The absence of strong moraines in most of the valleys is due, in part at least, to the vigorous cutting of the streams, which have long ago removed them. The Kennicott Glacier, which terminates near the mouth of McCarthy Creek, has remarkably little moraine around its edges, and although the surface of the lower portion of the glacier is covered with detritus the streams have removed this as fast as it has been dropped by the ice and in many places are cutting into the glacier itself.

Glacial till or bowlder clay is rather widely distributed in this area along the lower slopes of the valley walls. Its surface is generally covered by a heavy growth of mosses and timber, but fresh exposures can be seen at many places along the banks of streams. It consists of a rather dense blue clay in which are embedded bowlders, pebbles, and angular fragments of many different kinds of rock, and it is characterized by unassorted materials and lack of stratification.

BENCH GRAVELS.

As climatic conditions became less favorable for glaciation and the ice diminished from its greatest thickness the glaciers in many of the smaller drainage lines tributary to the larger trunk valleys shrank until they no longer joined the main ice lobes below. Thus the lower part of McCarthy and Dan creek valleys were free from ice while their mouths were blockaded by the Kennicott and the Nizina glaciers. In like manner the ice in the Chitina Valley had shrunk so that it was no longer able to override the ridges on either side of Young Creek, and Chititu and Young creeks had lost their ice while the Nizina Glacier still stood high in the valley to the northwest. As a result the drainage in many valleys was impeded by the ice dams across their mouths, and the streams began to fill in their basins with gravel deposits. It may be that temporary lakes were sometimes formed behind the ice barriers, but the character of the gravel deposited indicates that if such lakes existed they must have been of short duration.

Gravel fillings behind glacier dams in many places reached a great thickness. In Young Creek valley, above the portion where the creek flows north, the gravels are in places more than 500 feet thick near the center of the valley and thin out at the sides. The upper limit of the gravels is difficult to determine on account of the thick coating of moss with which the surface is covered, but it probably lies for the most part between the elevations of 3,250 and 3,500 feet. In Chititu Creek, at the mouth of Rex Creek, a similar thickness of gravels was reached. At the point where Dan Creek emerges from the mountains a great bench more than 700 feet high shows that the stream floor was graded up to that level when the Nizina Glacier still filled the valley below. In the McCarthy Creek valley a broad area was filled with gravels deposited under similar conditions. An advance by the Kennicott Glacier of only 2 or 3 miles would be sufficient to cause McCarthy Creek to begin again the grading up of its valley with gravels like those of which the gravel benches are composed.

In all of the valleys mentioned the alluvial filling was due to the presence of an ice barrier which retarded the drainage and caused the streams to build rapidly. As the great glaciers retreated and their thickness decreased the barriers to the tributary streams were lowered and they began to cut into the gravel filling which they had laid down. They did not, however, remove the filling from the whole width of the valleys, but intrenched themselves in this filling and developed deep gorges with gravel banks. Throughout much of the upper part of Young Creek and in parts of Chititu, Dan, and McCarthy creeks the streams have now cut completely through the gravels and into the rock below, leaving the valley filling as terraces or benches on either side of the streams. In Young Creek valley, especially, many lateral tributaries have also cut through the gravels, which now form interrupted benches along the slopes to the north and south of the stream.

PRESENT STREAM GRAVELS.

The larger glacier-fed streams of the area are in sharp contrast, both in appearance of water and in character of valley deposits, with the streams which do not head in active glaciers. The streams which are supplied only by melting snow and by the ordinary run-off are for the most part clear, and they are gradually cutting their valleys deeper. The glacier-fed streams, on the contrary, are supplied with great quantities of detritus by the glaciers, and during the warm season they are turbulent and heavily loaded, so that they are constantly building up their valleys with gravels and silts brought down from above. The Nizina Valley is a conspicuous example of this building process. The present flood plain ranges in width from one-fourth mile at the extreme western edge of the area mapped to more than 2 miles at its widest points. The flat is composed of gravel bars, for the most part bare of vegetation though some of the higher portions are timbered. The proportion of the flat that is covered by water at any one time not only varies greatly with the seasons, but often there is a great daily range as well. Since the water supply is largely furnished by the melting of the glaciers and of the snow on the mountains, the streams are highest in July, and in periods of high water a large part of the flat is covered. During the late fall and winter the rivers dwindle until but little water flows beneath the ice. The daily range, too, is largely controlled by the temperature, the streams being lowest in the early morning but on bright, sunny days increasing in volume until the late afternoon, when the flow is many times as large as it was early in the day.

All of these variations in volume are important factors in the transportation and deposition of débris. In high stages the streams are most turbulent and great quantities of gravel and silt are carried by them. In low stages the water becomes clearer and but little material is moved. As a result of their overloaded condition during the summer, the streams, which flow in some places as single streams and in others as intricate networks of channels, are constantly shifting their courses over the flood plains, building up bars in some places while cutting them away in others. In the Nizina Valley below Young Creek the present tendency of the river is to lower its bed, owing to the increased gradient given by the cutting down of Nizina Canyon below. Above Young Creek the valley floor is being built up, the building proceeding most rapidly at the mouths of the tributary streams. Chititu Creek has a large low-grade fan below its canyon, but the edge of this fan has reached the Nizina flood plain at only one point. Dan Creek also has a low fan extending out to the Nizina bars. The largest deposit from a tributary stream is that at the mouth of Chitistone River. Here a wide fan of low slope has crowded Nizina River over against the rock cliffs on its west valley wall, where in places all the talus slopes have been removed and the flood plain extends flush up against the limestone cliffs. This fan has also been effective in retarding the current of Nizina River above it and in aiding deposition there.

McCarthy Creek flows for the lower 10 miles of its course through a more or less narrow valley intrenched into the gravel deposits and into its rock bed, but above this portion the valley floor is broad and gravel filled.

POSTGLACIAL EROSION.

The agencies of rock weathering and erosion are very active in this region of great daily ranges in temperature, high altitudes, and steep slopes, so that the amount of rock material which has been removed since the retreat of the great glaciers has been large. The timber line throughout the district lies at about 4,000 feet or lower, although willow and alder bushes flourish above this and are sometimes found up to an elevation of 5,000 feet. Above 5,000 feet vegetation is sparse and most of the surface is bare and exposed to the agencies of weathering. Large talus slopes occur below all steep cliffs. The greenstone is perhaps most resistant of all rocks in this vicinity, and the talus accumulations below greenstone outcrops are small as compared with those below similar cliffs of the more easily weathered rocks. The Chitistone limestone follows the greenstone in its ability to resist weathering, although, as is to be expected, there are often large talus slopes below the enormous cliffs which this limestone offers. The porphyry weathers much more rapidly than either greenstone or limestone, and the sides of those mountains which are composed of this rock are almost invariably buried beneath great talus aprons. In the steep-sided porphyry mountain between the Kennicott and McCarthy Creek the talus is so abundant that few outcrops occur below an elevation of 5,000 feet and only the upper craggy portion of the mountain is free from talus. Both Triassic and Jurassic shales weather readily, the latter with the greater ease on account of its freedom from hard beds of limestone. A great amount of postglacial stream cutting has been done in the Triassic shales between McCarthy Creek and the Nizina. In the Kennicott shales of Dan, Chititu, and Young creeks the amount of stream cutting near the gulch heads has been very large. There is every reason to believe that on the south side of Chititu and on both sides of Young Creek the slopes were left smooth and free from gulches by the glacial ice. Since the ice retreated large gulches have been cut and a great amount of the easily eroded shale has been removed. The streams in these valleys have also succeeded in cutting through the thick gravels into the bed rock below.

Altogether, when the comparatively short time that has elapsed since the retreat of the ice from this area is considered, the work accomplished by erosional agencies has been surprisingly great.

ROCK GLACIERS.[a]

Among the important agencies of postglacial denudation in this district are the remarkable features which have been called rock glaciers (Pl. III, in pocket). These are rather widely distributed among the more rugged portions of the area, more than 30 occurring within the borders of this sheet. They are known to occur in other parts of the Wrangell Mountains, but here they attain exceptionally perfect development. An inspection of the topographic map shows at once many of the characteristics of the rock glaciers, but the important features, such as the surface markings, can not be shown with such a large contour interval. Although differing greatly among themselves in size, shape, and material, they have certain characteristics in common. They are usually long, narrow flows, many times longer than wide, confined in the bottoms of cirquelike valleys. Some have wide, fan-shaped heads and taper down to narrow tongues below; others are narrow above and spread out into spatulate lobes below; but the greater number are bodies of nearly uniform width, from one-tenth to one-fourth of a mile wide and from one-half to 2½ miles long. The surface slopes vary in different examples from 9° to 18° for the whole course of the flow.

On viewing one of the better-developed rock glaciers one is struck by its great resemblance to true glaciers. They all head in cirques and extend thence down the valleys. In cross section their shape is much like that of a glacier, being highest above the valley axis and sloping down sharply on the sides. Where confined in narrow valleys the rock glaciers are narrow tongues lying in the valley bottoms, but upon emerging from their restricting walls they spread out into broad lobes. Some have distinct lateral moraine-like ridges and all show a more or less well-marked longitudinal ridging.

The materials of which the rock glaciers are composed are the blocks and fragments of angular rock such as go to make up the ordinary talus slope, the fragments being derived from the walls of the cirque at the valley head. The variety of rock found in any

[a] Capps, Stephen R., Rock glaciers in Alaska: Jour. Geology, vol. 18, pp. 359–375.

rock glacier therefore depends on the materials found in the cirque walls—porphyry, limestone, greenstone, or shale, as the case may be. The individual rock fragments vary in size from fine stuff to blocks several feet in diameter in exceptional cases. Six inches would perhaps be the average size in these rock glaciers which are composed of porphyry, while in the greenstones and limestones the average is larger and in the shales it is smaller than this.

In many of the rock glaciers the fragmental rock extends all the way to the head of the cirque, with no ice visible and little or no snow on the surface. In several cases, however, the rock glaciers grade into true glaciers at their upper ends, without any sharp line of demarcation, so that there is a complete gradation between the two.

The surface markings are characteristic and in some measure are systematic in their arrangement. In the upper portions there are usually many parallel longitudinal ridges a few feet high, separated by troughlike depressions (Pl. IX, *B*, p. 56). Toward the lower end of each rock glacier which has an opportunity to spread out into a broad lobe the longitudinal ridges become less prominent and finally disappear entirely, giving place to concentric wrinkles which parallel the borders of the lobe. The sides of the flow below the cirque are usually separated from the rock valley walls by a sharp trough, and at their lower ends the flows steepen to the angle of rest for the material. The whole appearance gives one a decided impression of movement, as if the material had moved forward from the cirques in somewhat the manner of a glacier, the longitudinal lines simulating moraine lines.

The marked resemblance of these flows to glaciers led to the suspicion that ice must be in some way responsible for their movement. To determine if this were the case, a number of the rock glaciers, 7 or 8 in all, were dug into, and in each instance clear ice was found. This was not massive ice like that of a glacier, but interstitial ice, filling the cavities between the angular fragments and forming with the rock a breccia, with the ice as the matrix. The depth below the surface at which ice was found varied according to the elevation of the rock glacier and to the portion of it examined. Toward their lower ends the ice lay too deep to be found by any shallow excavations that there was opportunity to make. Farther up, toward the cirques in which they head, the ice was usually found within a foot or two of the surface if a depression was dug into. The surface of the ice-filled portion, being determined by the depth to which melting takes place, follows roughly the surface of the flow, so that along the troughs between the ridges running water could be found on a warm day following shallow channels in the ice-filled talus.

The rock glaciers are quite different from true glaciers, although in those cases where the rock glacier is a continuation of the lower end of a true glacier it may be impossible to draw a line separating the two. For the formation and existence of a glacier it is necessary that in the head of the basin occupied by ice there should be an annual surplus of snowfall over melt. When the amount of snowfall becomes less than the amount which melts and runs off, the glacier will dwindle and finally disappear. The greater number of rock glaciers, on the other hand, are found to head in cirques in which all or practically all of the winter snow disappears during the summer. In a true glacier, no matter how heavily moraine covered it may be, there is always a tendency to crevasse where the ice rounds a bend or passes over an irregularity of its bed, and great irregularity of surface is common at the lower end, where the melting ice allows the overlying moraine to cave in. In the rock glaciers no crevasses were seen, even in places where abrupt changes in the grade of the bed occur, and large cave-in pits are wanting. Irregularities of this kind, however, are not to be expected if the rock glaciers are composed, as they seem to be, of talus, with ice only in the interstices, for the talus itself is self-supporting without the ice, and the shape of the surface would be but little changed if the ice should all melt out. This is true, however, only of those flows which have not glaciers at their upper ends. Of those which head in glaciers, the upper ends would of course be profoundly altered by the melting of the ice, and these effects would be seen just as far down the flow as massive glacial ice had existed. The rock glaciers differ from true glaciers in that, although they advance spasmodically, they never retreat, for the flow retains its form even after the ice has melted out and motion has ceased. Little has been published concerning features of this kind. Certain "stone rivers" in the Falkland Islands have been described by Thomson,[a] Andersson,[b] and others, but according to Andersson's interpretation these "stone rivers," which are now streams of angular blocks of rock, were formerly composed of fine mud, with the blocks of rock buoyed up and carried along by the viscous flow of the mud. The movement has now ceased, and much of the fine material has been removed by running water.

The closest analogy to the rock glaciers seems to be found in the "rock streams" of the San Juan Mountains of Colorado, described by Cross and Howe[c] in the Silverton folio and more recently by Howe[d] in a separate publication. Both are composed of angular

[a] Thomson, Wyville, The Atlantic, p. 245.

[b] Andersson, J. G., Solifluction, a component of subaerial denudation: Jour. Geology, vol. 14, 1906, pp. 91–112.

[c] Cross, Whitman, and Howe, Ernest, Silverton folio (No. 120), Geol. Atlas U. S., U. S. Geol. Survey, 1905, p. 25.

[d] Howe, Ernest, Landslides in the San Juan Mountains, Colorado: Prof. Paper U. S. Geol. Survey No. 67, 1909.

talus from high mountains, and the similarities of appearance and surface configuration are striking. The San Juan flows have been referred to in a textbook[a] as "talus glaciers," and the authors are of the opinion that in many cases snow and ice have had some part in their development. Cross and Howe formerly believed that the position and form of the rock streams were due to glacial transportation, but the absence of ice and some other considerations led them to the opinion which they now hold, that the rock streams were formed by landslides which came down "with a sudden violent rush that ended as quickly as it started." Up to the present time no opportunity has offered to prove conclusively by a series of observations extending over a considerable period of time that these rock glaciers are in motion or to determine their rate of movement. There are, however, a number of significant facts which seem to make this conclusion necessary.

Although on account of climatic conditions most of the cirques in which the rock glaciers head are unable to support true glaciers, they are on the border line of glacial conditions, and although the snows may all melt away on the surface during the summer the ground remains permanently frozen a short distance below the surface and ice in the interstitial openings of a talus mass may remain unmelted indefinitely. Furthermore, a few of the rock glaciers have true glaciers at their heads which extend downward as far as climatic conditions are favorable and are continued below by rock glaciers whose ice is protected from the sun by the heavy coating of débris, and into such rock glaciers it is probable that a tapering tongue of true glacial ice extends down a considerable distance. But this glacial ice is not necessary to their movement, as is shown by those rock glaciers which are unconnected with true glaciers. In addition to the favorable climatic conditions, the exceptionally perfect development of these features in the Nizina district is due to the rugged character of the mountains, with cirques having steep heads and sides, and to unusually favorable conditions for rapid rock weathering and talus accumulation.

The history of the rock glaciers of this district is considered to have been as follows:

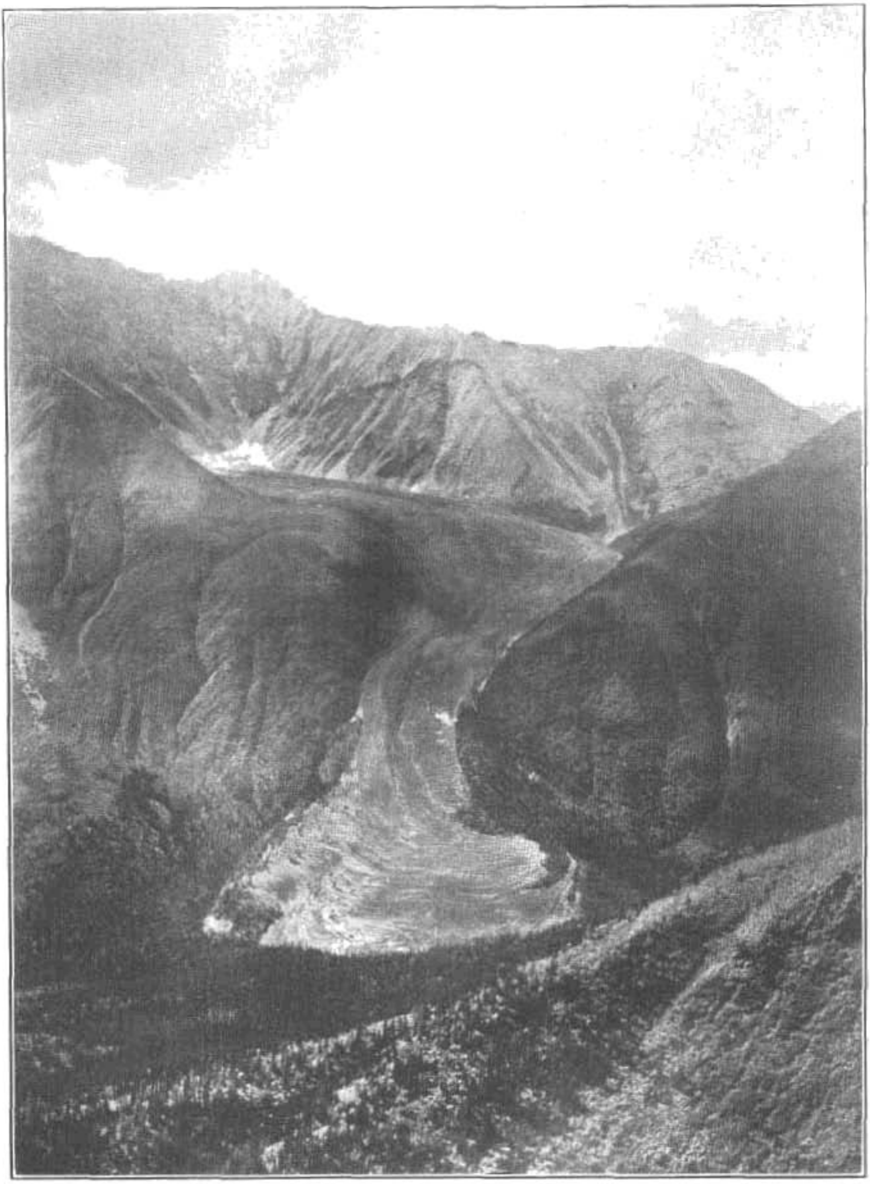
As the ice of the last great epoch of glaciation began to retreat and its area to contract, the head and side walls of many of the cirques, steepened by glacial undercutting and by bergschrund sapping, were exposed to the rapid weathering characteristic of bare rock surfaces in the high altitudes of this region. In many of the cirques the rock waste streamed down from the cliffs upon the glacier below and was gradually carried away by the ice and concentrated at its lower edge. Here in the usual order of events it

[a] Chamberlin, T. C., and Salisbury, R. D., Geology, vol. 1, 1904, p. 220.

would have been deposited as a terminal moraine, though differing in character from the common forms of terminal moraine in the preponderance of angular, talus-like material and in the proportionately smaller amount of mud and rock flour which form so important a part of the moraines of active glaciers. Here the small, fast-dying glaciers were eroding but little and were almost overwhelmed by the débris supplied them from the cliffs above. Into the débris toward the lower edge of the glacier the waters from melting ice and snow and from rains sank and froze and gradually filled the interstices up to a point below the surface where melting equaled freezing. In these ice-cemented masses a sort of glacial movement was started. As the climate became still milder, in many cirques the winter snows all melted away during the summer, so that conditions for ordinary glacial activity no longer existed, but the bodies of talus which reached the cirque floors became filled with interstitial ice and the consequent movement of the mass in a glacier-like way has continued, although no doubt all true glacial ice has now disappeared from many of the rock glaciers. It is certain that much snow is still carried down upon the surface of the rock glaciers in slides of snow and rock during the winter and spring, and considerable quantities of it may become covered by débris and incorporated into the rock glaciers, but this snow probably forms only a small part of the total mass of the flow.

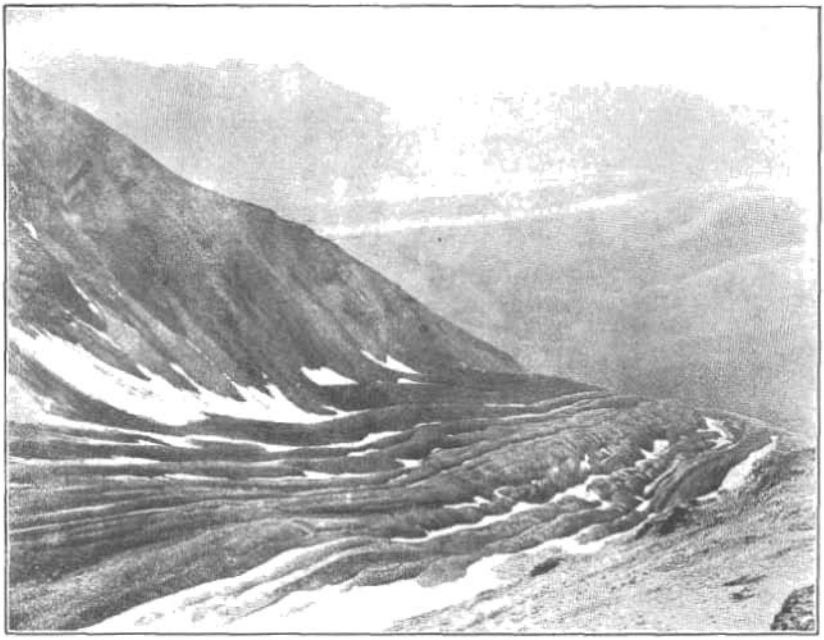
The succession of events outlined seems to be well established in this region, where are now to be seen all the stages, varying from apparently active glaciers with short rock glaciers below to long rock glaciers in which no glacial ice is seen, in valleys where all the snow disappears during the summer; yet in these latter the slow movement seems still to be in operation, the rate of movement in each flow being controlled by the supply of talus from above and by the shape and grade of the floor over which it moves. The rock glaciers are therefore the true successors of real glaciers.

The rock glacier which lies on the west side of McCarthy Creek, three-fourths of a mile above the mouth of East Fork (Pl. VIII), though by no means the largest in size, offers a most instructive example for study, as it presents in a typical way many of the characteristic features of all of the flows. It heads in a glacial cirque in a mountain composed largely of porphyry but having many inclosed masses of black shale, the peaks at the cirque head reaching a height of 6,315 feet. The rock glacier occupies the cirque floor below an elevation of 5,250 feet, with talus slopes extending upward above it for about 200 feet. Above the talus the whole face of the mountain is of bare, rugged cliffs of porphyry and shale, both of



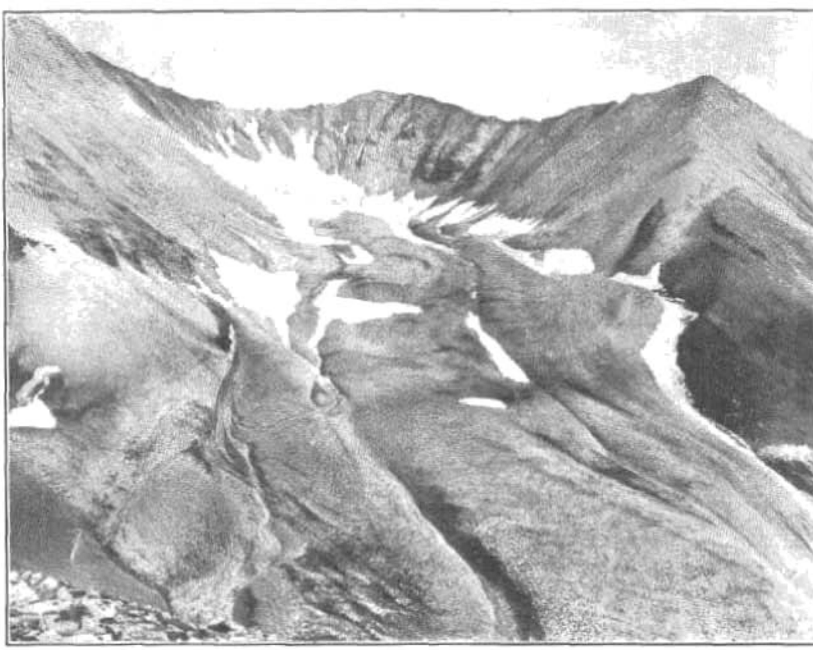
ROCK GLACIER ON McCARTHY CREEK THREE-FOURTHS OF A MILE ABOVE MOUTH OF EAST FORK.

Showing the source of supply in the talus cones above, also the surface markings—longitudinal in the upper portion, concentric below. See page 56.



A. ROCK GLACIER NEAR HEAD OF NATIONAL CREEK.

Showing the characteristic longitudinal ridges and their relation to the talus slopes on the rock walls above. See page 57.



B. HEAD OF ROCK GLACIER ON LITTLE NIKOLAI CREEK.

The cirquelike valley, with its abundant talus slopes feeding down to the rock glacier, is free from true glacial ice. See pages 53, 57.

which weather easily, so that the formation of talus is unusually rapid. The elevation of the valley head is not sufficient for the maintenance of a true glacier, and during the summer practically all of the snowfall disappears. By July 4, the time of observation, only small snow banks remained in sheltered places.

The rock glacier heads in the talus cones which have been built up at the base of the steep rock cliffs. These cones, although constantly added to by waste from the rapidly weathering cliffs above, have nowhere been able to attain large size, the materials evidently having moved on down the valley as a rock glacier as fast as they were supplied from above. From the base of each of the more vigorous talus cones a smooth ridge extends down the rock glacier, seeming to show that the forward movement has on the whole been uniform and continuous. Parallel longitudinal ridges of this kind characterize the surface of the upper three-fourths of the flow. The cirque basin above an elevation of 4,000 feet is a hanging valley, but below this level it joins the broad U-shaped valley of McCarthy Creek with an abrupt change of gradient. As it passes over the lip of the hanging cirque the rock glacier cascades steeply down the valley side, and on reaching the gentler slope below, being no longer confined by restricting valley walls, it spreads out in a great lobe along the valley bottom. In this lower lobe the longitudinal surface markings dwindle out and disappear, giving place to a set of beautifully developed concentric wrinkles which parallel the borders of the lobe (Pl. IX, *B*). The origin of these wrinkles is not clear, but they strongly suggest rings of growth and may represent the amount of annual movement of the rock glacier.

At its foot the flow has pushed across the valley bottom to the base of the east valley wall, thus indicating clearly by its position that it was formed after the retreat of the McCarthy Creek Glacier beyond this point. The creek has been crowded to the east and occupies a narrow channel between the foot of the rock glacier and the rock valley wall. The foot of the flow is being rapidly cut away by the stream and in places shows a face 75 to 100 feet high in which the slope is about 35°, or the angle of rest for the material. The creek, although of large volume and steep gradient, has been unable to do more than keep its channel open along the foot of the rock glacier, and it seems evident that the flow is moving forward as fast as the stream can cut it back.

Another rock glacier which heads in the same porphyry-shale mountain as the one just described flows in a northwest direction into the valley of National Creek, a tributary of the Kennicott (Pl. IX, *A*). It is remarkable for the unusually strong development of the longitudinal ridges in its upper portion, and these ridges show well their mode of origin in the separate talus slopes on the rock walls above.

The flow in Amazon Creek, just east of the Kennicott Glacier, and that in the north head of White Creek are notable for their great length as compared with their width and for the uniformity of their slopes from one end to the other. The surface of the former has a slope of 15° and that of the latter 12°.

The rock glacier which heads in the limestone mountain half a mile northeast of the Bonanza mine and flows eastward shows at its upper end all of the characteristics typical of these flows, but at the mouth of the hanging valley in which it lies it streams down to McCarthy Creek as a symmetrical talus cone (Pl. X, *A*). If the material had come down suddenly as a landslide, no such perfect talus cone would have formed, and its presence indicates that the material of which it is composed was supplied slowly. Furthermore, evidence that this rock glacier is still moving is given by the fact that the talus is still being supplied at the head of the cone and is invading the patch of bushes on its side.

The two large rock glaciers, one on the south and one on the northwest side of Sourdough Peak, are both of the type which originates in narrow cirques but spreads out into broad lobes below the point where the cirque walls restrict it. The glacier on the south side of this mountain is especially noteworthy on account of the great expanse of the flow below as compared with the narrow limits of the cirque in which it originated.

In conclusion, observation has led to the belief that these rock glaciers have moved and that many of them are still moving in much the same way as glaciers, and that, although glacial ice may be and doubtless is present in a few of them, it is not necessary to the movement, which may be due altogether to ice in the interstices. Furthermore, there is no evidence that the flows came down suddenly as landslides, but there are strong reasons for believing that they moved down slowly. The facts and considerations which have led to the conclusion that the flows did not come down suddenly but slowly and that some of them are now in motion are noted below.

1. The remarkable resemblance in position and form of the rock glaciers to true glaciers in the immediate vicinity.

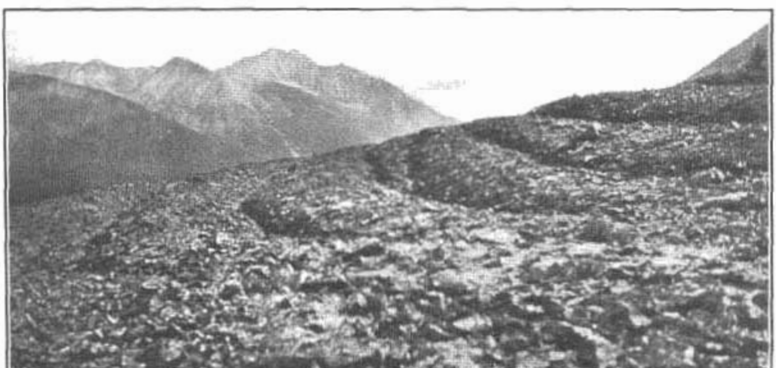
2. The direct connection and perfect gradation between true glaciers above and rock glaciers below.

3. The presence of interstitial ice at no great depth below the surface in all the rock glaciers which were dug into.

4. The longitudinal ridges of the upper portions of many of the flows that can be traced directly to active talus slopes.

A. ROCK GLACIER IN A TRIBUTARY OF McCARTHY CREEK NORTHEAST OF BONANZA MINE.

At the mouth of its hanging valley it breaks down into a great talus cone. See pages 58, 59.



B. DETAIL OF SURFACE OF ROCK GLACIER ON TRIBUTARY OF McCARTHY CREEK.

The rounded ridges in the foreground are the concentric ridges which characterize the lower portion of the flow

5. Nowhere have the talus slopes at the cirque heads been able to form any considerable accumulations upon the surface of the rock glaciers. This seems to be strong evidence that the talus has moved down valley as fast as it has been supplied.

6. Most of the rock glaciers have a steep slope at the lower end, where the gently sloping surface of the upper portion breaks down at the edge at an angle of rest as steep as the material will retain. On this steep face the rock fragments show bare surfaces, while the talus on the surface above is usually lichen covered. This seems to show that the material is moving forward fast enough to prevent erosion at the lower end from establishing drainage lines on the face of the flow and from reducing it to a low-graded slope.

7. McCarthy Creek, a swift stream of large volume, which is now actively cutting into the lower edge of a rock glacier on its west side (described on pp. 56–57) that has been in existence long enough for large spruce trees to grow upon its surface, has so far been unable to do more than keep open a narrow channel along the foot of the flow. There is no evidence that the rock glacier ever extended 75 feet farther eastward to the rock bluff on the east side of the valley. It would be surprising if this mass of material, coming down with a violent rush, should have failed by just the width of the creek to cross the valley, and if the stream, which is now actively cutting into the face of the flow, should have been unable to do more than keep its channel open. It appears more probable that the slowly advancing edge of the rock glacier had forced the stream to its present position and that the edge of the flow is now farther advanced than it has ever been before.

8. There is no evidence that large landslides have taken place in this region if these flows are not landslides. None were seen below the miles of prominent cliffs of the area, though ordinary talus cones are abundant.

9. The rock glacier on McCarthy Creek, northeast of the Bonanza mine (Pl. X, *A* and *B*), ends below in a well-developed talus cone. If the material had come down suddenly as a landslide, no such perfect talus cone would have been formed. The presence of the cone indicates that the material was supplied slowly, enabling the cone to grow symmetrically. The cone is still growing, as can be seen from the way in which the talus from above is invading the patch of bushes on its face.

10. Wherever two rock glaciers from adjacent cirques join to form a single flow the point of junction shows that the two branches have flowed together synchronously, without any evidence that the flow from one branch has come down and overridden that from the other.

IGNEOUS ROCKS.

TRIASSIC OR PRE-TRIASSIC.

NIKOLAI GREENSTONE.

CHARACTER OF THE FORMATION.

The Nikolai greenstone resembles a sedimentary formation in its structural features. It is made up of flows of basaltic lava that succeed one another like beds laid down in water. The beds or flows are usually of considerable thickness, measured in tens of feet rather than in single foot units, and the bedded appearance is more evident when a large mass of the greenstone is seen from a distance great enough to give a comprehensive view of its larger features.

The color of the weathered surface is grayish green, but in places it has a reddish hue. A fresh surface is dark olive or grayish green. In texture it varies from a dense, rough, fine-grained rock in which individual crystals can not be distinguished to a medium-grained porphyritic rock. Many of the flows are amygdaloidal and have a spotted appearance, due to the cavity fillings. Some of the spots or amygdules are light gray or almost white, like quartz or calcite; others are dark green or gray. Quartz is present but is not so frequently seen filling cavities as calcite, yet these two minerals are not the only ones that produce light-colored amygdules. Amygdaloidal greenstone bowlders in Chititu Creek contain large spherulitic aggregates of white crystals, believed to be thomsonite. This rock, however, was not seen in place. Dark-colored amygdules are more common than the light ones and for the most part consist of chloritic or serpentinous material. In many places the cavities of the lavas were elongated and distorted before their present mineral filling was introduced, so that the amygdules have peculiar irregular forms. The cavities appear to have been distributed throughout the flows from top to bottom, for no evidence of their being more abundant at the upper than at the lower surface was observed. This is one of the reasons for suspecting that the lava was poured out under water, since the weight of the water resting on the surface of the lava would prevent in large measure the expansion of included gases or steam; yet it is admitted that no proof of their submarine origin has been discovered. Interbedded tuffs and shales were not found in the greenstone. Frequently a weathered surface of the greenstone is seen where the amygdules have been dissolved out, leaving a vesicular rock that probably resembles closely the original lava flow.

A newly broken surface of the greenstone would hardly lead one to believe that chemical alteration had taken place to any considerable extent, for the rock appears to be fairly fresh, yet microscopic examination of the sections shows that the alteration is advanced and is general.

The Nikolai greenstone is less obtrusive in its topographic expression than either the shales or the limestone. It forms steep slopes and ragged mountain tops, but the greenstone mountains do not possess the sharp, angular outlines of the shale mountains or the high wall-like cliffs and the pointed spires of the limestone. Neither do the lower greenstone hills present the smooth, rounded contours of the glaciated shale ridges on either side of Young Creek. The greenstone resists decay, but it has numerous joints and fracture planes and rapidly breaks down under northern climatic conditions. This accounts for the roughness of its ridges, the absence of smooth perpendicular cliffs, and the vast quantity of angular blocks below its large exposures. Such blocks do not disintegrate like the shales, so that greenstone pebbles and bowlders form a conspicuous proportion of the gravels and other unconsolidated deposits. The greenstone, like the Chitistone limestone, resisted strongly the distorting forces that are so plainly expressed in the folding of the McCarthy shale. There is even less evidence of folding than in the limestone, but it is apparent from field observations that adjustment to pressure by faulting has taken place extensively.

PETROGRAPHIC DESCRIPTION.

Thin sections of greenstone studied with the microscope show that the rock is a typical diabase now much altered. The principal constituents are feldspar and colorless pyroxene. The feldspar is labradorite, occurring in lath-shaped crystals, and in nearly every section is more or less altered. Pyroxene fills the spaces between the feldspars. It has been less resistant to alteration than the feldspar and is largely altered to a serpentinous or chloritic material. Accessory minerals are magnetite or ilmenite and chalcopyrite; olivine and iddingsite are rare. The principal alteration minerals are serpentine or chlorite, calcite, and perhaps quartz.

Cavities in the greenstone were abundant, but have been filled with secondary minerals such as chlorite, delessite, calcite, and, rarely, quartz. Many of the amygdules show an outer coating of chloritic material and an inner filling of radiating delessite crystals, in some sections associated with calcite. An opaque decomposition product is common.

DISTRIBUTION.

The Nikolai greenstone underlies conformably the Chitistone limestone and took part in the folding and faulting that the lower part of the limestone underwent. Its distribution, therefore, is related to that of the limestone, and most of its outcrops represented on the map lie in a narrow belt on the south of the limestone belt that is practically continuous and extends southeastward from the northwest corner of the mapped area to the head of Texas Creek. This belt has its greatest width on Nizina River. A branch extends eastward up Chitistone River and then southeastward into the valley of Glacier Creek, a northwestward-flowing tributary of the Chitistone just beyond the eastern limit of the area mapped. The ridge between Dan and Glacier creeks is capped by a broad, flat syncline of limestone pitching gently northwest, but the base of this ridge wherever it is exposed is greenstone. Greenstone is exposed on both sides of Chitistone River. It dips below the gravel floor of Nizina River north of the Chitistone but rises to view again on the west side and continues north half a mile or more till it is cut off by a fault beyond the limits of the area mapped.

In places only a veneer of conglomerate or shale of the Kennicott formation covers the Nikolai greenstone and small isolated patches of the greenstone appear where the thin covering has been removed. Such patches are seen about National Creek and south of Nikolai Creek. Two small patches of greenstone appear as islands in the gravels of Nizina River, and another, exposed through faulting and erosion, lies on the north side of Copper Creek.

THICKNESS.

It is impossible to determine the thickness of the Nikolai greenstone from observations in the area under consideration, for nowhere within this area is the base of the greenstone exposed. Furthermore, it is not certain that the base of the greenstone is exposed in other parts of Chitina Valley, although it is reported in the Chitistone River basin, and it seems probable that certain tuffaceous and shale beds in the Kotsina Valley may represent it.

The figures to be given represent, therefore, only that part of the formation exposed immediately below the Chitistone limestone—that is, the upper part. One of the best localities for measurements is on the east side of Nizina River, just north of Dan Creek. The dip of the limestone and greenstone is low to the northeast. Unless the greenstone is reduplicated by faulting, its thickness at this locality is at least 4,000 and possibly 5,000 feet. The conditions for measurement in the mountain on the west side of Nizina River are less favorable, but there appear to be not less than 4,500 feet of greenstone exposed there. About 2,000 feet are exposed on the east side of McCarthy Creek and 3,500 feet in the ridge on which the Bonanza mine is situated. Between Bonanza Creek and Kennicott Glacier a thickness of over 4,000 feet of greenstone is exposed. Faults are difficult to locate in the greenstone unless some of the other formations are present to give a clue to their existence, and it is recognized that faults of sufficient importance to impair the value of the measurements given may have escaped notice. It is highly probable, however, that the thickness of greenstone in the Nizina district approaches 4,500 feet, and there can be little if any doubt that it is over 4,000 feet.

Schrader and Spencer estimated roughly the thickness of the Nikolai greenstone in the upper part of Kotsina Valley at 4,000 feet.[a]

AGE.

Inasmuch as the Nikolai greenstone is composed of lava flows and so far as known does not contain intercalated fossil-bearing beds, the determination of its age depends on its relation to the formations with which it is associated. The greenstone may perhaps contain intruded sills of rock similar in composition to the flows, but for the most part it is made up of lavas that were poured out before the Chitistone limestone began to be deposited. It can not therefore be later than Upper Triassic. Unfortunately no evidence has been collected to fix a lower age limit. North of the Nizina district, in the valley of Skolai Creek and about Skolai Pass and the head of White River, the massive upper Carboniferous limestone is overlain by thin shale beds, tuffs, and lava flows. These overlying beds are believed to rest on the limestone conformably. The lava flows increase rapidly in amount as the succession is followed upward until they finally predominate. There is a possibility that the Nikolai greenstone represents the upper part of these lavas overlying the Carboniferous limestone, in which case their age would be Triassic. Brooks and Kindle have presented evidence to show that Triassic sediments along the upper Yukon rest conformably on limestone of the same age as the limestone on White River.[b] There is therefore some degree of probability that a similar relation of Carboniferous and Triassic formations of the Wrangell Mountains may sometime be established. A comparison of the Nikolai greenstone with the rocks south of Chitina River is of interest but throws little light on the age of the greenstone. The rocks south of the Chitina are chiefly sediments, schists, graywackes, and limestones, all much metamorphosed rocks. Their age is not known but they are usually referred to the Paleozoic. The degree of alteration in them is far greater than in the greenstone, and if this fact may be used as evidence the greenstone is considerably younger. With our present knowledge it is hardly possible to say anything more definite concerning the age of the greenstone than that it is older than the Chitistone limestone and probably is Triassic.

[a] Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, Alaska: Special publication of the U. S. Geol. Survey, 1901, p. 42.

[b] Brooks, A. H., and Kindle, E. M., Paleozoic and associated rocks of the upper Yukon, Alaska: Bull. Geol. Soc. America, vol. 19, 1908, p. 305.

JURASSIC OR POST-JURASSIC IGNEOUS ROCKS.

QUARTZ DIORITE PORPHYRY INTRUSIVES.

LITHOLOGIC CHARACTER.

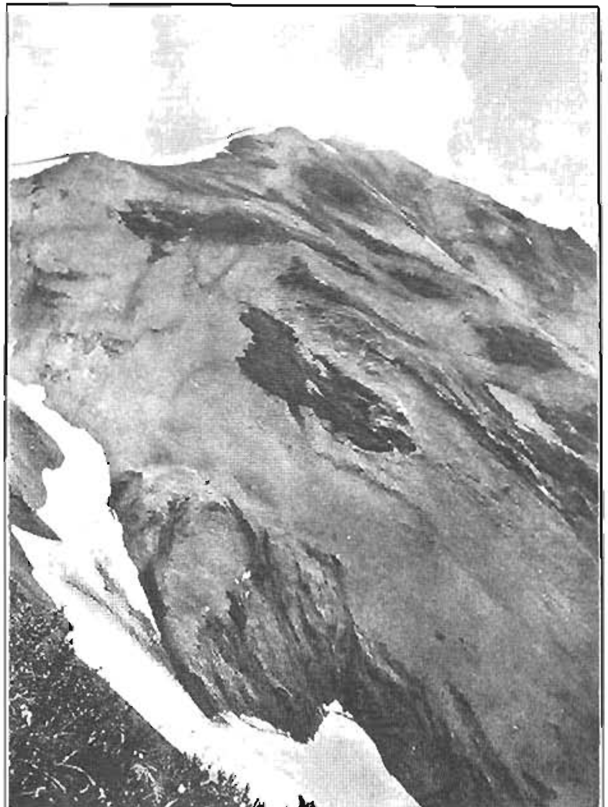
Light-colored porphyritic intrusive rocks are abundant in the Kennicott formation and are confined almost entirely to that formation, for it is a remarkable fact that intrusives are rare in the Triassic sediments and the greenstone. These intrusive rocks occur in the form of laccoliths, dikes, and sills. They show considerable differences in texture and vary from fine-grained, almost aphanitic phases to distinctly granular phases in which larger crystals or phenocrysts of feldspar and quartz are included. The color, too, varies from almost white to creamy white and various shades of gray and brown. Small phenocrysts of quartz with perfect crystal outlines are common, but as a rule the more abundant feldspar crystals are less distinct owing to chemical alteration that has taken place. It seems rather remarkable that the rock should be so fine grained as it is in some of the larger intrusives and that it should have had so litle effect on the shales into which it was intruded.

The porphyries show many stages of alteration, from intrusions that look perfectly fresh to those in which the feldspars are almost wholly decomposed and the rock has a dull, lifeless appearance. A curious banded arrangement of alteration products was noted in some of the light-colored, fine-grained intrusives. Different stages in the advancement of alteration are indicated by concentric zones of yellowish-brown and white color, which show that the chemical changes proceeded in an orderly way from the surface toward the center of each joint block.

In many places large masses of black shale have been caught up in the body of an intrusive and stand out in a most conspicuous way against the lighter-colored porphyry background (Pl. XI, *A*). Some of these intruded shale masses are half a mile in length along their outcrops and give the appearance of thin shale beds between very thick porphyry sills. In general, however, the included shale masses are much smaller.

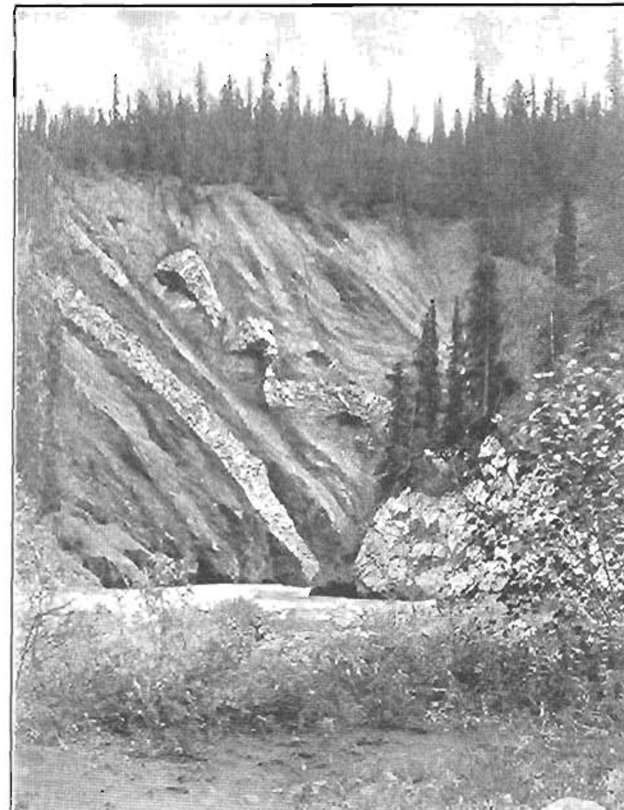
The porphyries resist decomposition but readily break down into slabs and angular fragments which give rise to extensive talus slopes, or "rock slides," as they are locally called. Such débris, because of its light color and its resistance to decay, gives character to slopes of loose material, and, although the dikes or sills from which it came may form only a minor portion of the rock mass, it almost completely hides the presence of shale or other kinds of rock.

Dikes and sills are numerous but present no unusual features further than that some of the sills persist for long distances and in



A. NORTH END OF PORPHYRY PEAK, SHOWING INCLUSIONS OF BLACK SHALE IN PORPHYRY.

See page 64.



B. PORPHYRITIC INTRUSIONS IN BLACK SHALE OF KENNICOTT FORMATION ON McCARTHY CREEK.

See page 65.

places take the form of long overlapping lenses. There is a marked tendency for the intruded rock to follow bedding planes rather than to cut across the beds, so that the sills are more numerous than dikes. Some of the sills in the black shales on the south side of Copper Creek valley continue uninterruptedly for several miles and are such distinct features that the prospectors have given them numbers, as the first, second, etc. They vary in thickness from a foot or two to 100 feet and give valuable aid in determining structure in the shales.

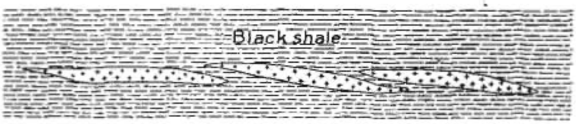


FIGURE 4.—Diagram showing the overlapping of lenticular porphyry sills in the black shales south of Copper Creek. Some of the lenses are 10 to 15 feet thick.

A good example of the way in which the porphyry dikes cut the black shales is given in Plate XI, *B*. (See also fig. 4.)

PETROGRAPHIC DESCRIPTION.

Microscopic examination of thin sections of the porphyry intrusives shows that perfectly fresh unaltered specimens are hardly to be found and that alteration products are practically always present. The rock has a fine-grained groundmass consisting chiefly of feldspar more or less altered and a little quartz in which are phenocrysts of feldspar and quartz. Various degrees of crystallization appear in the groundmass, but its perfection may be obscured by chemical alteration that has taken place since the magma consolidated. One or two of the sections studied are from specimens in which crystallization had not proceeded far when it was interrupted by cooling of the intrusive rock. These sections show a fine-grained groundmass, almost isotropic, filled with tiny forked skeleton laths or crystals of feldspar. Most sections, however, show a more advanced degree of crystallization. The feldspar is of the more acidic plagioclase variety. Zonal phenocrysts give an opportunity to determine that they belong mostly to the oligoclase-andesine series. Orthoclase appears in a few specimens. Quartz in rounded plates or with embayments is not uncommon, but for the most part the outlines are sharp and angular. Brown mica is usually present, as are also shreds and scales of colorless mica. Hornblende is the next most common ferromagnesian mineral. Many of the crystals are much altered, and in some sections the former presence of hornblende is known only by the decomposition products taking the form of the characteristic hornblende cross section. Pyroxene was found in one specimen. Most sections show a black metallic mineral like magnetite and brown iron-oxide stain.

Alteration begins in the feldspars and results in the production of fine scales of a highly refractory mineral, probably muscovite, that appear in fractures and along some of the zonal bands of the phenocrysts. Calcite is a common secondary mineral and results from the decomposition of hornblende and of feldspar, yet it may have been introduced in part by circulating water. Calcite resulting from decomposition of hornblende is associated with iron oxide.

DISTRIBUTION.

Porphyritic intrusions are present in the black shales of the Kennicott formation in all parts of the Nizina district, but they have their greatest development north of Nizina River. Porphyry Peak and Sourdough Peak are composed largely of porphyry, as is also the mountain north of Nikolai Creek. The upper parts of all three are made up almost entirely of porphyry in which are included masses of black shale. These laccoliths form a hard resisting cap on the softer shale base and doubtless have been an important factor in protecting the shale from erosion. There are no such large porphyry masses in the black shales southeast of Nizina River, but sills and dikes are numerous in all the shale mountains from Dan Creek to Young Creek. They appear to be more numerous on Dan and Copper creeks and about the head of Rex Creek than they are farther south, but the steep, bare sides of the mountains in the former locality give better opportunities for discovering them than the lower timber and moss-covered slopes of the latter. The preference shown by the intrusives for the black shales is considered as evidence that the molten rock was able to force itself into the black shales more easily than into the lower formations or the upper part of the Kennicott formation. It is remarkable, when one considers their number in the Kennicott formation, that so few intrusives are present in the Triassic sedimentary formations and the greenstone. Special attention was given to this point during the course of field work, since it was assumed that the intruding rocks must cut the older formations in order to reach the overlying younger formations and that traces of some of the conduits through which the melted rock rose would be found. A few dikes were discovered, but they do not seem to bear any proper relation in size and number to the amount of intruded matter in the shales, so that one is forced to conclude that the intrusives entered the shales through some channel not exposed.

AGE.

Intrusives in the Kennicott formation can not be older than the rocks into which they are intruded. Consequently they can not be older than late Jurassic or possibly early Cretaceous. No evidence bearing on their upper age limit was discovered in the Nizina district. It is perhaps true that the intrusions did not all take place at one time, and there might be cited as bearing on this point the fact that there is considerable variation in the composition and alteration of the intruded rocks. These two facts, however, are not in themselves proof. Such evidence as the intersection of one dike or sill by another dike or sill was not found, and it seems probable that the quartz porphyry intrusions belong to one period of intrusion.

Paige and Knopf have presented evidence to show that the quartz diorites of the Talkeetna Mountains are later than Middle Jurassic but younger than the late Jurassic, and state that they are "thus contemporaneous in a general way with that great series of batholithic intrusions of late Mesozoic age which affected the entire Cordilleran region from the Straits of Magellan to the Seward Peninsula of northwestern Alaska."[a] Quartz diorites of equivalent age intrude Upper Jurassic sediments in the Nutzotin Mountains northeast of the Wrangell Group.[b] There is a strong presumption that the quartz diorite porphyries of the Nizina district are but one manifestation of a disturbance that was widespread and of much greater importance in many other localities than it was here.

STRUCTURE.

Reference has already been made in the descriptions of the different formations to most of the structural features of the district, but for the sake of clearness these facts are here brought together in one section. Examination of the geologic map (Pl. III, in pocket) shows that in a general way the formations lie in zones extending in a northwest-southeast direction. Two sections are placed on the map to interpret the structure of these formations. They show that the prevailing dip of the formations below the Kennicott is toward the northeast but that the prevailing dip of the Kennicott itself is toward the southwest, and, further, that in consequence of the greater disturbances that have taken place in the older formations their general dip is considerably greater. Section *A–A* shows the synclinal structure of the Nikolai, Chitistone, and McCarthy formations along the northern boundary of the mapped area west of Nizina River. A parallel section northeast from any point on Dan Creek to Chitistone River or Glacier Creek would have shown this synclinal structure but with the syncline much flattened out, and a comparison of such a section with section *A–A* and the map would show that the synclinal axis pitches gently northwest. Section *A–A* also shows the unconformable relation of the Kennicott to the older formations, its comparatively low southwesterly dip, and the fault that here displaces the basal beds of the Kennicott and the Nikolai greenstone. Section

[a] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, p. 20.

[b] Moffit, Fred H., and Knopf, Adolph, Mineral resources of the Nabesna-White district, Alaska: Bull. U. S. Geol. Survey No. 417, 1910.

B–B shows the Kennicott formation dipping gently to the southwest in broad open folds. The southwest dip is small but is sufficient to bring the interbedded shale and sandstone forming the upper part of the Kennicott formation well down on the slope of the mountains south of Young Creek, although these beds appear only on the tops of the high mountains south of Copper Creek and about the head of Rex Creek. At the northeastern end of this section the greenstone and the limestone lie almost horizontally, but a displacement has taken place by which the limestone is brought into contact with the black shale of the Kennicott formation, and it appears that near the fault plane the limestone dips to the southwest or toward the fault.

Faulting is of common occurrence in the Nizina district, but with the exception of the fault shown on the two sections most of the displacements are comparatively small in amount. The great fault just referred to is a strike fault—that is, its trend is the same as the prevailing strike of the formations and it extends from Copper Creek northwestward to McCarthy Creek. From work done in previous years it is known that this great fault continues westward beyond the Kennicott Glacier, but its course there has not been traced.

Good opportunities for studying the fault were found at two localities, one on the South Fork of Nikolai Creek and the other on Dan and Copper creeks. The north slope of the South Fork of Nikolai Creek is a dip slope formed by a thin veneer of basal Kennicott beds resting on greenstone. (See section *A–A*, Pl. III.) The south slope shows the basal Kennicott in the creek with a narrow belt of greenstone above it and above the greenstone a great thickness of Kennicott dipping to the southwest. The Kennicott and Nikolai formations in this locality were displaced by a fault in such a way that the rocks on the south side now have a relatively higher position than those on the north side. The fault dips high to the northeast and the displacement is about 800 feet. Very different conditions prevail on Dan and Copper creeks. Section *B–B*, Plate III, shows that the north slope of Dan Creek is formed of Nikolai greenstone and Chitistone limestone lying in a practically horizontal position. This condition does not hold on the south side; instead a great block of limestone abuts against black Kennicott shales and forms the point of the obtuse angle between Dan and Copper creeks. In this locality the displacement involves a raising of the north side relatively to the south side, exactly the reverse condition from that in the Nikolai Creek locality. This fault dips about 60° NE. on Dan Creek and, although complicated by minor cross faults, has a displacement that seems to be nearly or quite the thickness of the Chitistone limestone.

The same relative movement as that on Dan Creek took place on the two sides of the fault on the west side of Kennicott Glacier—that is, the formations on the north side were raised—yet no direct evidence was discovered to prove the existence of the fault between the glacier and McCarthy Creek.

Faults of this kind in which the relative movements of the two walls are opposite in direction at two different localities are known elsewhere, yet, inasmuch as the gravels of Nizina River prevent the demonstration that the Dan Creek fault is continuous with that of Nikolai Creek, it should be stated that the conditions described might result from the dropping of a block between two parallel faults, in which case we should be dealing not with one but rather with two faults. No evidence was seen in the field to raise a suspicion that two closely spaced faults occur here. A perpendicular fault almost parallel with the Dan Creek fault traverses the Young Creek valley, and a third, whose strike is more nearly east and west, crosses Nizina River a short distance north of the limits of the area mapped. The Young Creek fault is probably of the same order of magnitude as that of Dan Creek but is more difficult to study, since only one formation is concerned in the localities where it was examined. It has a known horizontal extension of 5 or 6 miles and the zone of disturbance is a wide one. These displacements, however, throw no light on the problems of Dan and Nikolai creeks.

The three faults just mentioned are the most prominent ones of the Nizina district, but they are not the only ones. There is evidence in many places of movement of the greenstone and limestone formations along their plane of contact, but measurements of displacement under such conditions are difficult. Undoubtedly faults are present in many places where they have not been recognized, for it is only under favorable conditions that they are discovered. Such conditions are provided by the limestone-greenstone contact. The character and frequency of faulting are shown on the geologic map by the contact north of Dan Creek. Displacements of the kind occurring there are difficult to recognize and to trace where only one of the formations is present. Most of the observed minor faults make obtuse angles approaching 90° with the major strike faults and are vertical or nearly so. They are present in many places and are commonly of small displacement in comparison with the strike faults even when of considerable horizontal extension. The shear zone of the Bonanza ore body is of this class. It was traced in a direction N. 30° E. from the mine for a distance of 1 mile, but the displacement at the limestone-greenstone contact is only 2 feet. A parallel fault on the east side of McCarthy Creek has a displacement of over 500 feet. The numerous faults north of Dan Creek are vertical or nearly so and have displacements ranging from 10 or 15 feet to several hundred feet. Minor strike faults were also noted, but since they do not cut bedding or formation boundaries they are apt to be undiscovered, as are also faults of low dip, such as the horizontal fracture planes of the Bonanza mine, along which slight movement has taken place.

In summarizing what has been said about faulting attention is directed to the fact that in a broad way the faults may be divided into two classes, those parallel to the prevailing strike of the formations and those that are approximately perpendicular to it. These may be referred to as strike faults and dip faults, for they are vertical or approximately so, and their strikes correspond in a measure with the direction of strike and dip of the formations.

The principal strike faults have given rise to great displacement of the rocks cut by them and persist for long distances horizontally. The dip faults are more numerous but the displacements are smaller. The effects of these faults on the rocks may be compared to the fracturing of the ice in a glacier. Blocks were formed which had to adjust themselves to surrounding conditions; some of them moved up, some down, as will be seen by examining the limestone-greenstone contact north of Dan Creek. In this way adjustments of great amount were brought about by many small, widely distributed displacements.

AREAL GEOLOGY.

The areal distribution of each formation has been indicated in the description of the formation. It now remains to bring these scattered facts together in one brief statement. Fully one-third of the mapped area is occupied by unconsolidated gravels, sands, etc., of glacial and fluvial origin (Pl. III, in pocket). Two-thirds of the remainder is given to the Kennicott formation. Consequently less than one-fourth remains to the rocks older than the Jurassic. The greenstone, the limestone, and the Triassic shales are confined strictly to a belt along the northeastern side of the area, but their territory is invaded in a few places by outliers of the overlying basal beds of the Kennicott formation. Triassic shales occupy only a small part of the area belonging to the older rocks, for the map does not extend far enough north to include the places of their greatest development. They are seen along the boundary of the mapped area between McCarthy Creek and Nizina River and in the vicinity of Copper Creek. The Nikolai greenstone and the Chitistone limestone form a narrow belt that extends northwest from Pyramid Peak to Kennicott Glacier. Nothing but Kennicott sediments and the igneous rocks intruded in them appears south of the Triassic formations. They appear in two principal areas on the two sides of Nizina River and are separated by a broad stretch of gravel deposits. Quartz diorite porphyries cut the Kennicott sediments in all parts of the district but find their greatest development in the black shales, particularly the shale area north of Nizina River. The porphyry sills of Copper Creek are conspicuous because of their persistence, but the intrusives of Porphyry and Sourdough peaks are so much greater in amount that they dominate in the upper parts of these mountains.

It may not be out of place to state here that the four formations of the Nizina region continue northwestward beyond Kennicott Glacier and that their areal relations there are practically the same as on the east side. Black Kennicott shales with numerous porphyry intrusives make up the mountains west of Porphyry Peak on the opposite side of Kennicott River, and the greenstone and Triassic sedimentary formations appear north of Fourth of July Pass. The mountain in the middle of the glacier, known as "The Peninsula," gives an excellent section of the greenstone and the two Triassic formations. Greenstone forms the southern point of "The Peninsula." On it lies the northeastward-dipping limestone, which is succeeded in turn by the Triassic shales. This locality is one of a few in this region where the limestone has been closely folded and much contorted.

It is known regarding the extension of these formations toward the southeast that the greenstone outcrops on Canyon Creek east of Young Creek, and it is probable that both greenstone and limestone extend still farther eastward into the Chitina Valley. Schrader traced the black Jurassic shales, which were at first thought to be Triassic, as far east as Canyon Creek, but beyond that there is no information concerning them.

HISTORICAL GEOLOGY.

SEDIMENTARY AND IGNEOUS RECORD.

In describing the formations of the Nizina district the rocks of sedimentary origin were considered in one group and those of igneous origin in a second. This treatment by family groups is not followed in the discussion of the historical geology of the district, but rather it is attempted to give in the order of their occurrence the geologic events connected with the different rocks.

The first event in the geologic history of the district concerning which we have evidence within the district is the outpouring of lavas that are now known as the Nikolai greenstone. This took place previous to the deposition of the Chitistone limestone, and consequently either in Upper Triassic time or in some period preceding it. It is not, probable, however, that the greenstone flows are older than the Triassic, since the best evidence at hand indicates that they are later than Carboniferous. The flows did not take place as a single event but were doubtless continued through a considerable time interval. There is some reason to believe that they may have been poured out under water, although it is by no means established that such is the case; yet, whether they accumulated in the sea or whether they accumulated on land and were later carried below sea level by subsidence of the land, the beginning of deposition of Upper Triassic marked the complete cessation of volcanic activity for the time being. Deposition of the Chitistone limestone continued for a long interval of time without important changes in the character of the material laid down. At first the conditions of accumulation were relatively stable and the massive beds at the base of the Chitistone were formed, but later conditions changed, for the beds grew thinner, and finally thin partings of shale began to appear. The commencement of shale deposition marked the beginning of the transition from the Chitistone limestone to the McCarthy shale. As the shale beds increased in amount the limestone decreased, till finally shale predominated and limestone was no longer of importance in the formation. All these events that concern the sedimentary formations took place before the end of the Triassic period. They terminated with an elevation of the Triassic sediments above sea level, which was accompanied or followed by deformation and folding of all the sedimentary beds and the greenstone. Erosion of the new land surface began as soon as elevation took place and, unless part of the historic record has been lost or overlooked, continued throughout Lower and Middle Jurassic time. During this erosion period an enormous quantity of material was removed from the land and returned to the sea, but what became of it is not known. The beveled edges of the greenstone, the limestone, and the shale bear evidence of an areal extension of these formations beyond the limits now recognized and testify to the thousands of feet of material carried away.

Erosion was at last interrupted by the advance of the Jurassic sea. This advance probably took place from the west, where it began in Lower Jurassic time, as is known from the presence of Lower Jurassic beds on Cook Inlet. Upper Jurassic sea prevailed in the Chitina region long enough to permit many thousand feet of sediments to accumulate. This sea is supposed to have been a somewhat restricted one. The waters were shallow. Probably a land mass existed to the south in the region of the present Chugach Mountains and separated the sea from the ocean. The sediments deposited in the Jurassic sea are not all of one kind and were deposited under varying conditions. The Kennicott formation bears within itself evidence of many and important changes during the time when it was being laid down. Shore conditions are indicated by the basal conglomerate, but the gradual upward decrease in size of the pebbles that form the conglomerate and the transition from conglomerate or grit to sandstone and from sandstone to fine black shales tell of a progressive change in conditions that is difficult to interpret, for it may have been caused in various ways. The great thickness of fine black shale, however, is evidence of long-continued stability in the source of supply and the manner of deposition of the materials composing them. Stability at last gave place to instability, and another great thickness of interbedded shales and sandstones followed the black shales till the last known event of Upper Jurassic deposition took place and the massive upper conglomerate was laid down. Deformation, elevation above sea level, and intrusion by quartz diorite porphyry are the next events recorded in the rocks of the mapped area, and they lead up nearly to the beginning of development of the present topography. Yet there is reason for assuming that the Kennicott formation does not represent the latest rocks of the Nizina district and that other younger sedimentary and igneous rocks may have once been present but are now entirely removed. This assumption is based on the presence of coal-bearing beds and still younger lava flows in the vicinity of Fourth of July Creek, west of Kennicott Glacier, and on the head of Chitistone River. Neither of these localities has been studied in detail. The coal of Fourth of July Creek is confined to a small area. It lies horizontally, is associated with black carbonaceous shale, and is overlain by arkose sandstone and an andesitic lava flow. Its relation to the great fault that cuts the Kennicott and older formations is such as to leave little doubt that it was deposited after faulting took place, and it is provisionally referred to the Tertiary. Coals associated with shales and sandstones and overlain by lava flows are exposed on Chitistone River. These beds also are referred to the Tertiary. The presence of these younger rocks in the immediate vicinity makes it appear highly probable that they may have extended into the region under consideration, since it is difficult to understand how they could have been deposited where they now appear without being much more widespread than they are. A coal-bearing formation consisting predominantly of coarse arkose and showing no evidence of marine conditions, but included between marine Tertiary formations, reaches a thickness of more than 2,000 feet in the Controller Bay region.[a]

More than 3,000 feet of fresh-water coal-bearing Tertiary sediments are exposed in the Matanuska region.[b]

These sediments comprise "a series of sandstones, shales, arkose, numerous coal seams, and a large volume of conglomerate." The Gakona formation of the Copper River basin[c] is a coal-bearing for-

[a] Martin, G. C., Geology and mineral resources of the Controller Bay region, Alaska: Bull. U. S. Geol. Survey No. 335, 1908, p. 31.

[b] Paige, Sidney, and Knopf, Adolph, Geologic reconnaissance in the Matanuska and Talkeetna basins, Alaska: Bull. U. S. Geol. Survey No. 327, 1907, p. 27.

[c] Mendenhall, Walter C., Geology of the central Copper River region: Prof. Paper U. S. Geol. Survey No. 41, 1905, p. 52.

mation of fresh-water origin. It reaches a thickness estimated to be not less than 2,000 feet and includes 500 feet of conglomerate, together with shale, gravel, sand, and lignite beds. Other areas of supposedly Tertiary sediments appear in the Copper River valley, but very little is known about them. If the coal-bearing rocks occurring just north of the Nizina district are of Tertiary age, it is a reasonable presumption in the absence of definite proof that they, like the coal-bearing Tertiary formations of the Matanuska and Copper River basins, are of fresh-water origin, and that therefore there is no necessity for assuming a submergence of the region below sea level after the Kennicott formation was deposited. The element of doubt in this presumption lies in the uncertainty concerning the age of the coal, for it is known that the Upper Jurassic formations as well as the Tertiary formations of the Matanuska region carry coal.

PHYSIOGRAPHIC RECORD.

There is good evidence in many parts of Alaska to show that at the time when the Tertiary coal formations were deposited the land had a much lower relief than it has to-day. The present mountain ranges, although perhaps distinctly outlined, had not yet reached their full development. The coal formations were laid down in depressions of a land surface that must have lacked in large measure the rugged character that we now see. Probably this land surface presented many of the features of the present Copper River or Yukon valleys in their broader parts. Such appear to have been the conditions when the forces that resulted in the uplifting production of the present Chugach Mountains and the Alaska Range began to be felt. These forces doubtless acted slowly, but they acted for a long period of time, and they may be in operation yet. They brought about the uplift of the mountain areas and made it possible for the agents of erosion to initiate the work of forming the present mountain and valley features. They were accompanied by or were the cause of the extrusion of a great volume of lava that has continued almost to the present day and is the most characteristic feature of the Wrangell Mountains, the feature that distinguishes them from the Chugach Mountains on the south and the Alaska Range on the north.

Chitina Valley is a very old topographic feature and was formed by a stream that probably had an outlet by way of the upper Copper River valley either into the drainage basin of Cook Inlet or possibly into the Yukon Valley. Its axis coincides with the boundary line between the older metamorphic rocks of the Chugach Mountains and the younger, less-altered rocks on the north side of the valley. This boundary in part marks an unconformity of deposition and possibly also one of faulting, but in either case it appears to have been a determining factor in locating the position of the valley. The valleys of Nizina River and the other streams of the Nizina district, like the Chitina Valley, originally represented the work of streams alone and were the result of normal stream erosion, but they have been profoundly modified by the action of glacial ice. This modification is represented chiefly by changes in valley forms due to straightening of the sides, alterations in the form of cross section, and lowering of the valley floors, together with changes brought about by the deposition of unconsolidated glacial materials. These modifications having already been described in the section on glaciation, it is unnecessary to repeat their description here. It is only necessary to say that the most conspicuous topographic features we see to-day owe their present appearance to recent glaciation, yet that subsequent stream cutting and rapid subaerial erosion due to the subarctic conditions have begun to modify the land forms left by the retreating ice. These later features are seen in the rock-walled canyons on the lower courses of all the streams, the deep gulches such as cut the Kennicott formation on White and Young creeks, and the great accumulations of loose material in the form of talus.

ECONOMIC GEOLOGY.

HISTORY.

The history of mining in the Chitina Valley begins with the rush of prospectors to Valdez in 1898. These men were influenced by the gold discoveries in the Yukon Basin during the preceding two years and came to Valdez in the hope of finding an easier route to the Yukon or new placers in the Copper River valley. Reports of copper on Copper River had circulated since the time of the Russians, who found in the hands of natives copper that probably came from the Nizina district, yet a majority of the prospectors were in search of gold, not copper. A few, however, turned their attention to copper and crossed from Valdez to the Wrangell Mountains, where their efforts received encouragement. In the following year (1899) the search for valuable minerals was resumed and prospecting parties ascended Chitina Valley as far as the Nizina district. It is doubtful if they attempted to go farther east in the main valley, and for that matter there has been little effort to prospect the upper Chitina region in the years since then. The Nikolai copper lode was shown to a party of white men by a native sent for this purpose by Chief Nikolai, of Taral, in July, 1899. Nikolai's house was at the mouth of Dan Creek, and the ore body was doubtless discovered by the natives on some of their hunting expeditions. It is usually difficult to reconcile the statements of different persons concerning the early events connected with the history of a new country, and the Nizina district is no exception to the rule. It is said that gold was discovered on both Dan and Young creeks at about this time, but either the quantity found was small or the difficulties met prevented any immediate steps toward developing the property.

Work was begun on the Nikolai mine in 1900 for the purpose of securing a patent to the claim. Some of the men who were interested in the property devoted part of their time to further prospecting, and in this way the large body of chalcocite named the Bonanza ore body was discovered about the end of July or the first of August (1900) by C. L. Warner and Jack Smith. It was discovered independently a short time later by Spencer, of the United States Geological Survey, who was engaged in mapping the contact of the Nikolai greenstone and the Chitistone limestone. Up to this time interest in gold placers had been secondary to that in copper prospects, but the presence of gold on Dan Creek was not forgotten, and in 1901 the creek was staked by C. L. Warner and D. L. Kain for themselves and others. Mr. Kain was known to his companion as "Dan," and they named the creek after him.

The first men to find gold on Chititu Creek were Frank Kernan and Charles Koppus, who came to the creek in the first part of April, 1902. They were joined shortly afterwards by two others, Messrs. Rowland and Dimmet, and these men staked the creek for themselves and their partners on April 25. News of the Nizina strike quickly reached the outside, and by July of 1902 the stampede was under way. A new town sprang up on Chititu Creek and was quickly provided with all the usual elements of a thriving placer camp, but there was not enough placer ground to support all comers, and most of the population soon vanished. The richest and most easily mined gravels were largely worked out in the first years by pick and shovel, but since that time the claims on both Chititu and Dan creeks have become more and more consolidated in the hands of a few owners, who are preparing to handle their gold-bearing gravels on a larger scale by more economical methods.

A similar consolidation of ownership has taken place in the case of the Bonanza mine, so that now instead of 11 principal ownerships, some of them representing two or more persons, the property is controlled by a single strong corporation capable of supplying the large capital necessary to develop the ore body.

The mineral production of the Chitina Valley to the present time consists entirely of gold, which is practically all from Chititu and Dan creeks. Copper has not been produced in a commercial way because there is no means of getting it to the coast, so that all the copper brought out is that taken for samples and assays.

COPPER.

OCCURRENCE OF THE ORES.

GENERAL STATEMENT.

An examination of the copper prospects of the Chitina Valley was made by members of the United States Geological Survey in 1907, and a report of that work was published in bulletin form later.[a]

Since that time there has been considerable advancement in the development of some properties and a few discoveries have been made, yet the results of the work done have thrown no light on the nature of the changes which take place in the ore bodies as distance from the surface increases. This question, excepting that of the amount of ore present, is probably the most important one concerning the copper deposits of the region. A study of the copper deposits on the eastern side of the Wrangell Mountains[b] has shown that copper occurs there under much the same conditions as in the Chitina Valley and has suggested some further ideas as to the origin of the ores. The descriptions and discussion that follow, then, are based partly on previous work but have received such revision and addition as have been found to be necessary.

Copper ores in the Chitina Valley north of the river occur in three ways—as copper and copper-iron sulphides associated with the Nikolai greenstone and with the Chitistone limestone; as native copper associated with the greenstone; as placer copper accompanied by native silver and gold. The important copper minerals are chalcocite or copper glance, bornite, chalcopyrite, and native copper. In every copper prospect there is a small quantity of one or more of the oxidation products, such as green malachite stain, azurite, and less frequently the red oxide, cuprite. Chalcanthite, or blue copper sulphate, and the black oxide, tenorite, are rare. Covellite is associated with chalcocite in some localities.

The ore bodies occur as replacements of greenstone or of limestone or as fillings in cavities developed along fault planes, shear zones, or joint planes in greenstone or limestone. A few examples are known of ore bodies to which the term "fissure vein" might be applied in its popular sense, but by far the greater number of the copper deposits are aggregates of copper minerals forming ore bodies of irregular shape which are well described by the term "bunch deposits," yet even the "bunch deposits" are believed to owe their existence to the presence of faults or fractures that permitted the circulation of copper-bearing solutions. Aggregates of copper min-

[a] Moffit, Fred H., and Maddren, A. G., Mineral resources of the Kotsina-Chitina region, Alaska: Bull. U. S. Geol. Survey No. 374, 1909.

[b] Moffit, Fred H., and Knopf, Adolph, Mineral resources of the Nabesna-White district, Alaska: Bull. U. S. Geol. Survey No. 417, 1910.

erals are far more common in the greenstone than in the limestone, but the largest deposits that have been discovered up to the present are in limestone. Most of the deposits in limestone are near the base of the Chitistone formation, yet there are a few notable exceptions to this general rule. On the other hand, the attempt to show that deposits in the greenstone are most apt to occur near or at the limestone-greenstone contact was not successful, and the field evidence seems to indicate that copper occurs in nearly all parts of the formation and that the location of ore bodies is dependent only on favorable conditions of supply or for deposition.

COPPER SULPHIDE DEPOSITS IN GREENSTONE AND LIMESTONE.

Although this part of this paper is intended to deal only with the copper prospects of the Nizina district, it is necessary in the description of the ores to consider the district in its relation to the rest of the Chitina region. The best examples of copper sulphides in greenstone are not found within the region under consideration but to the west of it. The copper minerals are bornite, chalcopyrite, and chalcocite, with secondary alteration products, and they occur (1) in irregularly shaped ore bodies without any conspicuous amount of associated gangue minerals or (2) as well-defined veins accompanied by a gangue of calcite and quartz. Ore bodies of the first kind occur in shear zones or in jointed or shattered portions of the rock. The copper minerals fill fractures in the rock, or more commonly they replace the rock itself. Bornite and chalcopyrite are of more common occurrence than chalcocite, yet some of the most promising ore bodies in the greenstone consist chiefly of chalcocite.

A careful examination of the many copper prospects leads to the belief that most of the ore bodies are of the "bunch deposit" type and are a replacement of the greenstone by copper minerals carried in solutions that circulated along fracture planes produced by jointing, shearing, or faulting of the country rock. The mineralized parts of the greenstone are without definite boundaries in many places, and the ore grades from solid sulphides to disseminated grains or particles scattered through the greenstone, which grow fewer and fewer as distance from the fractures increases till they disappear altogether. Sections of ore examined under the microscope show that the two sulphides bornite and chalcopyrite are closely associated and are intermingled in such a way as to suggest that they were deposited at the same time. Chalcopyrite is practically always present, even in ore that appears to the naked eye as pure bornite. Chalcocite accompanies the bornite and chalcopyrite in some specimens, and the association is such as to suggest that the chalcocite was derived from the poorer sulphides, but this was not definitely proved. A few of the deposits in greenstone consist entirely of chalcocite.

The vein deposits accompanied by gangue minerals are associated with well-defined faults in all the best examples. The copper minerals are bornite and chalcopyrite, and the gangue is chiefly calcite accompanied by quartz. Epidote is commonly present also. The veins pinch and swell markedly in short distances and in all the localities where they were examined have been subjected to faulting or other movement since their deposition.

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 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 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.

NATIVE COPPER ASSOCIATED WITH THE GREENSTONE.

Native copper is associated with amygdaloidal phases of the Nikolai greenstone and is also found accompanied by quartz or by quartz and epidote in veins cutting the greenstone. Most commonly it occurs as grains and small slugs in the amygdules and disseminated through the greenstone and as films or leaves and small veinlets cutting the greenstone. Tabular masses deposited in joint planes without much doubt indicate the way in which the large masses of native copper and the copper nuggets in the Dan and Chititu placers were formed. Such masses found in place on the head of White River are believed to have resulted from the alteration of chalcocite. In a few places in the tributary valleys of the Chitistone and Kotsina rivers native copper occurs in amygdaloidal greenstone in association with a mixture of copper oxide and carbonaceous matter, filling vesicles and fractures in the lavas. Such native copper as is known in the Nizina district is probably due to the reduction of previously formed sulphides or oxides, yet primary native copper is known on the head of White River. There is a strong similarity between the native copper-bearing greenstone of Chitina Valley and the amygdaloidal copper ores of Lake Superior. Specimens from the two regions could be selected between which it is doubtful if close observation could distinguish. This similarity would also extend to the disseminated sulphide ores in greenstone if by any means the sulphides could be altered to native copper.

PLACER COPPER.

Native copper is associated with silver and gold in the gravels of Chititu and Dan creeks. It occurs in pieces that range in size from fine shot to masses weighing several hundred pounds. Two or three tubs of fine copper are secured at each "clean-up" of the sluice boxes on Chititu Creek and give much difficulty in cleaning the gold, since the finest of the copper has to be removed by hand. Many of the nuggets contain native silver, which shows that the copper and silver are here closely associated in origin. The remarkable similarity in form and appearance between the copper nuggets of the Nizina district and the larger masses of copper taken from the stamp mills of the Lake Superior region is evident to anyone who compares the two, since the chief differences are that the placer copper has a slightly smoother surface and an oxidized coating. The copper and silver are derived wholly or in part from the greenstone. Assays of chalcocite from the Bonanza mine and from other copper ores of the Nizina district have shown the presence of both silver and gold in the copper deposits. Small particles of native silver were found in a freshly broken specimen of greenstone from a bowlder on Chititu Creek, and an assay of the rock also showed its presence. The silver was associated with calcite in small fractures. Silver nuggets up to 7 pounds in weight have been found on Dan and Chititu creeks, but where silver is associated with copper in the same nugget copper predominates, and in general silver is seen only as small particles in the copper. Copper is found only in those tributaries of Dan and Chititu creeks where greenstone pebbles and bowlders form part of the stream gravels; consequently it occurs only where the gravels have been formed in part by streams flowing through greenstone areas or where there is a foreign element in the gravels that was derived from a greenstone area and brought to its present position by glacial ice.

ORIGIN OF THE COPPER DEPOSITS.

It is not yet possible to give a satisfactory account of the origin of the copper deposits, but some features of their history can be stated with a considerable degree of certainty, and it is desirable to do this, since it may be of value in future development work. A history of the present deposits is concerned chiefly with three problems—the source of the copper minerals, the manner in which they were brought to their present position and deposited, and the changes that have taken place in them since they were deposited.

It is believed that the source of the copper is within the Nikolai greenstone itself and that only a very small part, if any, is derived from an outside source. The chief argument in favor of this view is the widespread and almost universal occurrence of copper minerals in the greenstone wherever it is exposed. This is seen in hundreds of places in all parts of the formation, from the west end of the Chitina Valley to Nizina River and the upper Chitina. Wherever fractures in the greenstone have permitted water to circulate the green copper stain is apt to be found. Probably the copper was originally present in the form of sulphide in the lava flows, but this does not exclude the possibility of its also having been combined in other minerals of the rock. Pyrite and chalcopyrite are of common occurrence in the greenstone, as is proved by both the hand specimens and the thin sections examined under the microscope. This source is believed to be adequate for supplying all the copper concentrated in the present ore bodies.

An examination of the greenstone in many places has shown that considerable chemical alteration in its constituent minerals is universal. No fresh and unaltered specimens of the rock were found. Alteration began first and is greatest in the pyroxene, and in many places this alteration is complete, so that there now remains only a mass of chloritic or serpentinous material. The feldspar has suffered less, yet the changes are advanced. Opaque masses of brown iron oxide appear to represent original grains or crystals of pyrite or chalcopyrite. These changes have resulted in the production of chloritic and possibly serpentinous material, calcite, quartz, and delessite. In places zeolites as thomsonite have been produced, but they are comparatively rare in the Nizina district and the region to the west, although they are abundant in amygdaloids of the White River region.

Changes of the kind mentioned are usually considered to be accomplished through the agency of circulating water. Chemical changes in the minerals of the basalts were made possible by the presence of water and the substances carried in solution. By the same means copper minerals were taken into solution and redeposited under favorable conditions. It is a noteworthy fact that the Wrangell Mountain region has been one of volcanic activity since Carboniferous time at least, and, although it has not been possible to establish a direct relation between the copper deposits and any igneous rocks of later age than the Nikolai greenstone, it is not unreasonable to suppose that the presence of heated rocks in the near vicinity may have had an important influence in promoting circulation in the greenstone and particularly in increasing the solvent power of the circulating water.

As to the manner of deposition, it is believed that the copper taken into solution by circulating water was carried into trunk channels and deposited there when the conditions were favorable. Speculations as to the exact chemical changes that took place are of very doubtful value with the present knowledge of the facts and will not be attempted. Most frequently deposition took place in the greenstone formation, but at times the copper-bearing waters passed outside the greenstone and into the overlying limestone before giving up their mineral load. As a rule, the ore bodies were not formed by the deposition of copper minerals in open cavities, although openings sufficient to permit a circulation of water were necessarily present. Most of the ore is a replacement of the country rock itself by copper sulphides. The replacement of greenstone is more nearly complete adjacent to the openings through which water passed and grows less and less as the distance from the openings increases. On the other hand, most of the limestone ores show a complete replacement of the limestone without any outside zone of disseminated sulphides.

Examination with the microscope has shown that bornite and chalcopyrite are usually associated in the greenstone deposits, even in bornite ores that show no chalcopyrite to the unaided eye. This fact, together with the manner in which chalcopyrite is scattered through the bornite, might be taken as presumptive evidence that the bornite was derived from chalcopyrite and is a secondary enrichment. This fact alone does not amount to proof, but the seeming increase in chalcopyrite as depth is gained in some of the bornite-chalcopyrite veins, such as the Nikolai vein, lends some weight to the presumption. The presence of native copper associated with chalcocite and bornite also points to the same conclusion, since native copper is usually regarded as of secondary origin. On the other hand, no evidence was found in the chalcocite deposits in limestone, such as that of the Bonanza mine, to indicate that the ore body has ever been anything other than what it is at present. The copper sulphide appears to have been deposited as such, and a careful examination of the ore has failed to discover the presence of other minerals than those produced by alteration of the chalcocite. It is doubtful if secondary enriched ores could form under the conditions now prevailing at the Bonanza mine, since all openings such as are due to joints and other fractures are filled with ice, as is also the loose talus material below the mine on both sides of the ridge. Furthermore, the breaking down of the ore and of the limestone inclosing the ore body under the climatic conditions of this region proceeds faster than oxidation. The exposed ore on the ridge and loose broken-down ore on the talus slopes show only a thin film of oxidized material on the surface. Yet thin veins of chalcocite in the limestone and even large masses of chalcocite have been almost completely altered to azurite, which shows that oxidation has taken place either under present conditions or, more probably, under earlier and more favorable conditions, possibly before the late ice advance.

The ore of the Westover claim, on Dan Creek, is an intimate mixture of chalcocite and bornite in silicified limestone along a fracture zone. The copper and copper-iron sulphides are disseminated through the rock in small grains and in veinlets cutting the rock. Most of the disseminated grains are chalcocite, but the veinlets and the larger irregular masses are a mixture of chalcocite and bornite. The veinlets are later than the quartz inclosing them and possibly later than the disseminated grains in the quartz, yet the minerals of the veinlets appear to be contemporaneous. These examples show how unsatisfactory is the evidence concerning the nature of the deposits, but they have some importance in that they do not promise greater richness in copper as the ores are followed below the surface. This point is emphasized because of the belief on the part of many prospectors in the Chitina region that the deposits will grow richer as they are more fully developed. The contrary is more likely to be true, for although they may continue with their present richness they are more apt to grow poorer than to grow richer.

DESCRIPTION OF PROPERTIES.

PRINCIPAL GROUPS.

The better-known copper properties of the Nizina district may be divided into three groups—first, the group in the vicinity of Bonanza Peak, including the Bonanza mine, the Jumbo, the Erie, and the Independence claims, together with the properties known as the Marvellous and Bonanza extension claims; second, the Nikolai Creek group; and, third, the group that includes the Westover claim and other neighboring claims north of Dan Creek. Many other claims have been staked, particularly along the limestone-greenstone contact, but there has been little development work done on them and they contribute little to our knowledge of the copper deposits of the district.

BONANZA MINE.

The Bonanza mine is the most valuable[a] copper property now known in the Copper River region. It is situated on the east side of Kennicott Glacier, at the head of Bonanza Creek, and is the property of the Kennicott Mines Company. Bonanza Creek proper and its western fork head in a glacial cirque basin on the west side of the high divide between Kennicott Glacier and McCarthy Creek. Its two forks include the high ridge on which the copper deposit is situated. The stream is about 3 miles long and flows in a southwesterly direction to the Kennicott Glacier. A post-office called Kennicott has been established at the mouth of National Creek, half a mile south of the mouth of Bonanza Creek and 4 miles from the mine, and the company's main camp and office are located at that place. A wagon road leads from the mouth of National Creek to a point about 500 feet below the mine and another follows the edge of the glacier south to McCarthy Creek. An aerial tram with a capacity of 100 tons per day has been constructed and loading and delivery stations have been built, so that the mine is now practically ready to begin the production of ore, although the storage bunkers are not completed and no ore can be shipped till the railroad reaches Kennicott.

An examination of the geologic map (Pl. III, in pocket) will make clear the general geologic conditions. South of National Creek the high ridge between the glacier and McCarthy Creek consists of black Kennicott shale intruded by large masses of light-gray porphyry. The Jurassic shales and intrusives are separated by an unconformity and probably also by a fault from the greenstone and the overlying Chitistone limestone on the north. North of National Creek the greenstone and limestone appear. The strike of the limestone is northwest and southeast, and its dip averages between 25° and 35° NE. It therefore cuts diagonally across the main ridge from McCarthy Creek to the glacier. Still farther northeast the Triassic shales overlying the limestone appear, but are not of any importance in connection with the copper.

The Bonanza mine is situated on a spur that runs out to the southwest between the forks of Bonanza Creek from the main ridge. This spur is crossed by the limestone-greenstone contact at a point about one-third of a mile from the main ridge. Where the boundary crosses the crest of this spur it has an elevation of 6,000 feet above sea level or 4,000 feet above the point at the mouth of National Creek where the tramway will deliver ore. On the northeast the spur

[a] Since the Bonanza mine was visited in 1907 much work has been done toward surface development and equipment of the mine for shipping ore, but work on the ore body itself has not been such as to add greatly to the knowledge of the deposit. For this reason the description here given is based largely on the previous description published in Bull. U. S. Geol. Survey No. 374.

WEST SIDE OF RIDGE AT BONANZA MINE.

The richest ore exposed on the surface is on the top and face of the ridge between the points indicated by arrows. See page 85.

rises rapidly till 1,000 feet in elevation is gained, but on the southwest its crest is almost horizontal for a distance of about one-third of a mile, beyond which it slopes away steeply to the forks of Bonanza Creek (Pl. XII).

The greenstone immediately below the ore body is variable in texture and general appearance. Part of it is amygdaloidal; porphyritic phåses are also present. Amygdules are not confined to the top of the flows but are present throughout from bottom to top. In some places they have been dissolved out on exposed surfaces, leaving a vesicular rock that looks like a recent lava. A bed of red and green shale having a thickness of about 5 feet intervenes between the greenstone and the overlying limestone. This shale forms a narrow northward-sloping bench for a short distance along the northwest side of the ridge, but is everywhere covered with talus and is found only when the débris has been cleared away. The bench is clearly indicated by the snow banks in Plate XII. The base of the limestone consists of not less than 40 feet of coarse gray, slightly argillaceous rock, whose broken surfaces are covered in many places with flattened cylindrical bodies that immediately suggest organic material of some kind. Several specimens of these bodies were submitted to Dr. T. W. Stanton, who says that they are probably corals but are too obscure for identification. Over this basal limestone is a bed a few feet thick of impure shaly limestone, and this in turn is overlain by dark and light-gray massive beds which carry the ore bodies. The limestone dip at the mine is slightly variable but averages about 22° NE.

The limestone is broken by numerous faults and fracture planes, the most prominent of which are nearly perpendicular and range in strike from N. 40° E. to N. 70° E. A minor set of fault planes with about the same strike dips steeply to the west. Another set runs in a northwesterly direction, and in several places striations on slickensided surfaces or clay seams show that the movement was horizontal. Fault planes with low dips, some of them nearly horizontal, are also present. None of the faults observed give evidence of much displacement, but together with the numerous joints they afforded an opportunity for mineral-bearing waters to enter the limestone. The principal fault planes—those running from northeast to southwest—form what may be described as a sheeted zone in the limestone that was traced north-northeast from the Bonanza mine for 1½ miles. This zone has a width of 50 or 60 feet and extends through the shale bed into the greenstone below, but is less noticeable in the greenstone than in the limestone. A vertical displacement of 2 feet occurs in the limestone-greenstone contact along one of the fault planes in the shear zone and is the maximum displacement observed.

The copper ore is chalcocite. Considerable azurite has been formed by oxidation of the chalcocite, and covellite is reported also. Covellite was not found in the specimens of ore collected from the Bonanza mine by the writers, but good specimens of covellite were collected from the Marvellous claim half a mile to the northeast, and its occurrence at the Bonanza is not questioned. The chalcocite is in veins or tabular masses of solid ore up to 5 or 6 feet in thickness, in large irregularly shaped bodies, and in stockworks in the brecciated limestone. Two principal veins of chalcocite are seen on the surface. They stand almost perpendicularly, 12 to 15 feet apart, and strike N. 41° E., forming the comb of the sharp ridge but crossing it at a slight angle, as the ridge at this place has a more nearly north-south direction than the veins. On the surface the veins do not extend down into the lower impure part of the limestone but end abruptly on reaching it. In places the precipitous northwest face of the ridge is plastered over with masses of solid chalcocite for a distance of 50 or 60 feet vertically below the top.

Azurite appears on the surface of the chalcocite and also as a lining of small vugs in the chalcocite, but it is present chiefly as thin veins, that form a network in the limestone and are doubtless due to the alteration of original chalcocite veins, for some of the azurite has an inner core of chalcocite. Azurite is more conspicuous than chalcocite in the surface network of veins in the northern 150 feet of the ore body, but chalcocite forms the great mass of the remainder. The ore bodies formed along the northeast-southwest faults of the northern part of the deposit are not the direct continuation of the large chalcocite veins at the south, but lie in nearly parallel veins which cut the ridge at a greater angle, their strike being about N. 60° to 70° E. The very rich ore can be traced on the surface for a distance of about 250 feet. It ends abruptly on the south in a nearly vertical limestone wall, but on the north gives place to the lower-grade ores, consisting of small veins of azurite and chalcocite with scattered masses of chalcocite, some of them weighing several tons. This lower-grade ore shows on the surface for a distance of at least 150 feet northeast from the high-grade ores, and small scattered azurite veins extend still farther in that direction. The ore, as it shows on the surface, therefore, extends northeast and southwest along the strike for a distance of 400 feet. The thickness, however, is more indefinite, but the very rich ore, with its included limestone, as seen at the surface, has a width of approximately 25 feet, although the thickness of ore sufficiently rich to be mined may be greater.

A little chalcocite and less bornite are found in some of the shearing planes in the greenstone, but they do not extend far into the greenstone. The quantity is small and inconspicuous and might readily pass unobserved. A small amount of epidote is associated with it in places. The main shear zone in the greenstone cuts an older set of quartz-epidote veins whose direction is about north-northwest. These veins do not intersect the limestone. They reach a maximum thick-

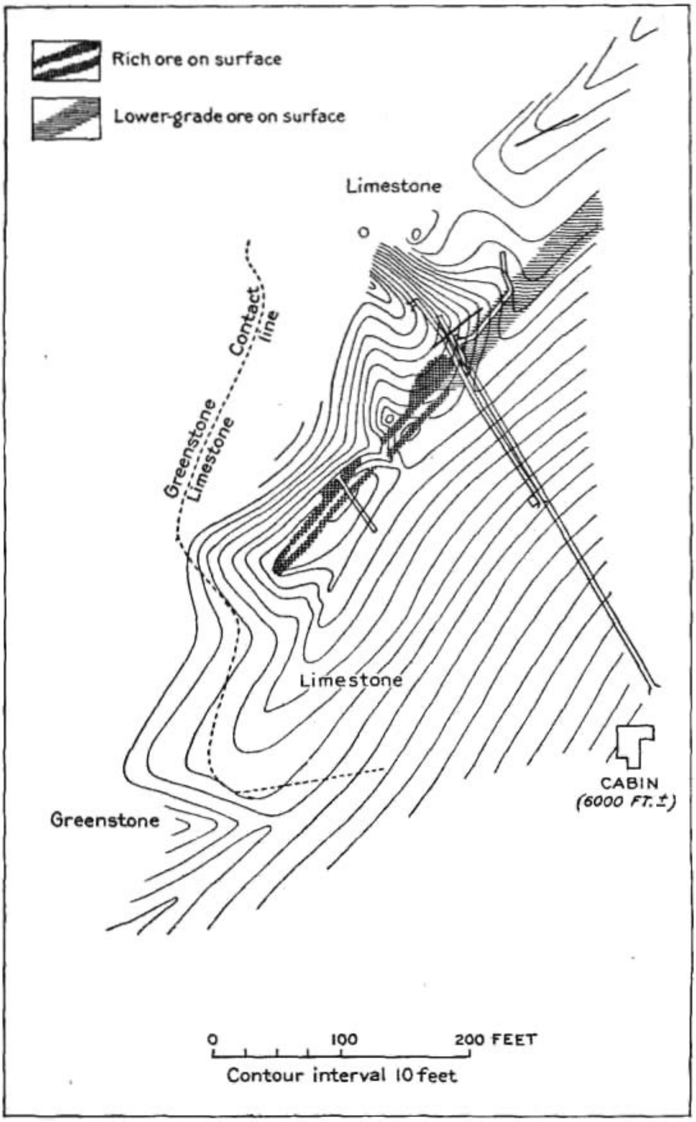


FIGURE 5.—Sketch map of the area near the Bonanza mine, showing the limestone-greenstone contact, the location of the richer ores on the surface, and the tunnels.

ness of 1 foot and carry small amounts of chalcocite, bornite, and native copper.

When the Bonanza mine was visited in 1907 two crosscuts (fig. 5) had been driven in the ore body in a direction N. 33° W. They are therefore not exactly perpendicular to it. The longer tunnel starts on the east side of the ridge and 75 feet below its top; it is 180 feet in length and extends through to the west side of the ridge. The richest ore, consisting of large masses of chalcocite with some included limestone, is encountered at a distance of 90 feet from the tunnel's mouth and continues for a distance of 21½ feet as measured in the roof. There are smaller bodies of chalcocite, however, for a distance of 10 or 15 feet on either side of the main ore body. About 115 feet from the entrance to the tunnel a winze 33 feet deep was sunk in the ore, and from the bottom a drift zigzags northward approximately 110 feet.

In 1909 a new tunnel had been driven below this longer tunnel from the southeast side of the ridge and connected by a raise with the winze. The new tunnel is 78 feet below the upper one and parallel with it. In July, 1909, it had been driven 45 feet beyond

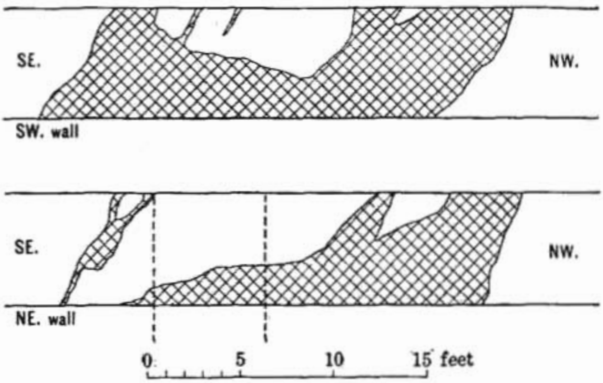


FIGURE 6.—Sketch showing form of ore body exposed in the upper northern tunnel at the Bonanza mine.

the raise but had not encountered any ore bodies as large as those of the upper tunnels. Several small lenses of chalcocite, the largest about 18 inches thick, were exposed in the tunnel itself, but the raise showed much more, for it cut the large body in which the winze was sunk. The absence of the large chalcocite bodies in the lower tunnel adds some weight to the opinion expressed after the visit of 1907 that the ore would probably not extend into the basal impure limestone beds.

About 120 feet southwest of this tunnel is a parallel tunnel driven from the west side of the ridge and 50 feet lower than the little saddle above it on the north. This tunnel starts in a face of solid chalcocite and extends S. 33° E. for 50 feet. The ore, which is chalcocite with a small amount of azurite, is exposed for 34 feet along the tunnel, but is interrupted by horses of limestone. The remainder of the tunnel shows limestone cut by small azurite veins and in places containing a small amount of chalcocite.

A better conception of the form of the ore bodies can be obtained by an examination of figures 5, 6, and 7 than can be given in a written description. The two main parallel surface veins afford only an imperfect idea of the deposit. Those two veins represent a total replacement of limestone along minor zones, where shearing was most intense. The two tunnels show that not only is the limestone replaced along the main shear zone but that mineralized waters followed minor fracture planes also, and thus yielded the low-lying ore bodies and great irregular masses seen underground. Between and around the large masses of chalcocite the limestone was shattered and filled with many small veins of ore, which formed a stockwork that is most noticeable in the winze tunnel and on the surface northeast of the main ore body. As a rule, the brittle chalcocite is very little fractured. The limestone, on the other hand, is greatly shattered and is filled with thin veins of calcite which are older than

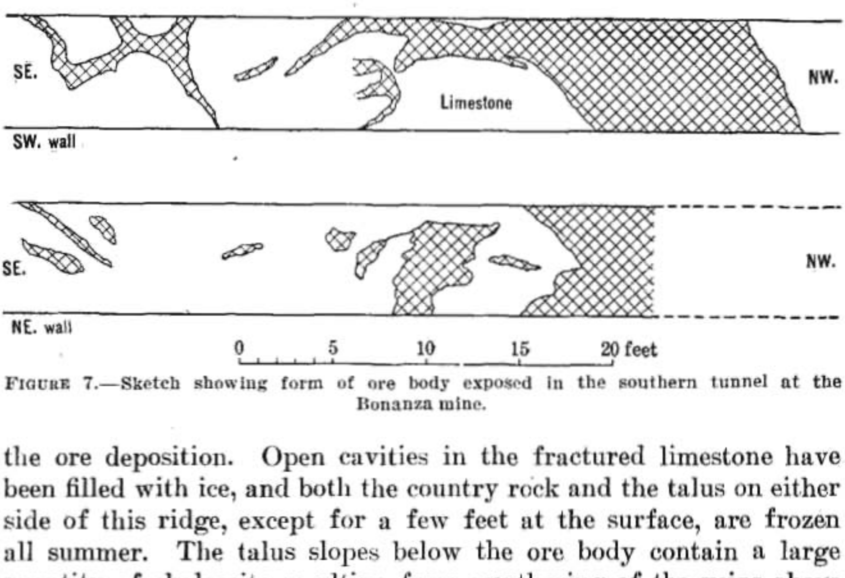
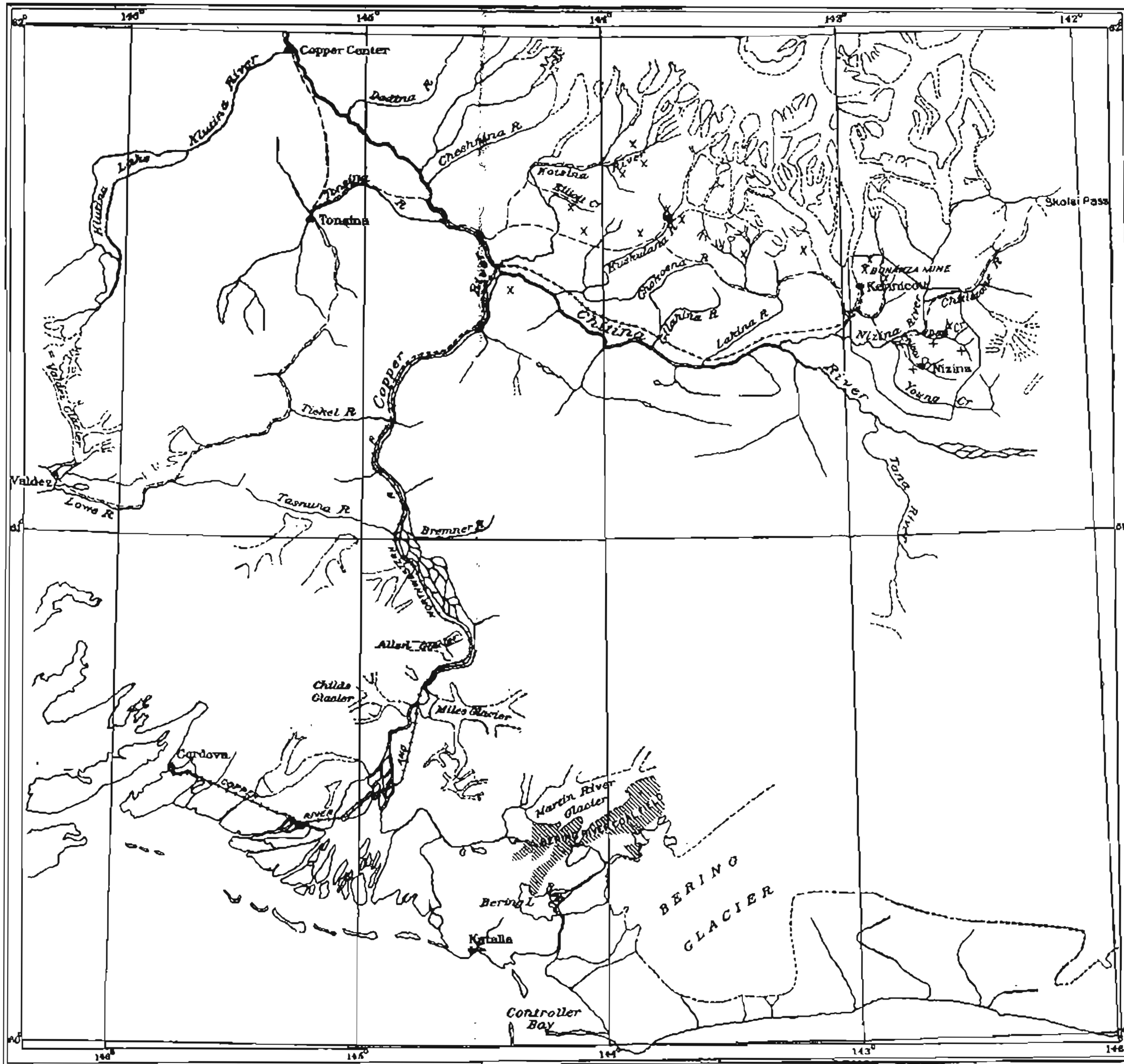


FIGURE 7.—Sketch showing form of ore body exposed in the southern tunnel at the Bonanza mine.

the ore deposition. Open cavities in the fractured limestone have been filled with ice, and both the country rock and the talus on either side of this ridge, except for a few feet at the surface, are frozen all summer. The talus slopes below the ore body contain a large quantity of chalcocite resulting from weathering of the veins above and are a valuable source of copper.

It is a suggestive fact that, although the main shear zone of the Bonanza mine extends from the limestone through the thin shale bed into the greenstone below, the large chalcocite bodies, so far as can be determined on the surface, end abruptly at the top of the impure shaly beds forming the lower 50 or 60 feet of the limestone. Copper minerals are associated with the shear zone in the greenstone, but only in small amount. Apparently the impure thin-bedded part of the limestone was a less favorable place for deposition than the purer massive beds above. This fact has a practical bearing on the quantity of ore present, for it is evident that if the same condition



10 0 10 20 30 Miles

X Copper prospect + Gold placer ——— Trail ------- Boundary of glaciers

MAP OF THE COPPER AND CHITINA VALLEYS, SHOWING LOCATION OF AREA REPRESENTED ON NIZINA SPECIAL MAP.

continues underground it limits the downward extension of chalcocite in the limestone. The continuation of the ore body to the northeast will probably be limited chiefly by the continuation of favorable conditions for deposition in the shear zone in that direction. The exact conditions which determined the deposition of the Bonanza ore body are not known; possibly it was the presence of a shear zone favorable to circulation; but its occurrence, together with that of the Jumbo and the Erie chalcocite bodies to the northwest, next to be described, indicates that favorable conditions for deposition have been established in more than one place and offer encouragement for seeking other chalcocite bodies at the base of the Chitistone limestone.

JUMBO CLAIM.

From the Bonanza mine the Chitistone limestone continues northwestward in a succession of lofty cliffs as far as Kennicott Glacier. The base of these cliffs is at the greenstone contact and in many places contains veinlets and stringers of azurite or chalcocite. In at least two places the quantity of these two minerals, especially of the chalcocite, is so great as to make the deposits of commercial importance.

The ore body of the Jumbo claim is 4,600 feet northwest of the Bonanza, at the head of Jumbo Creek, and is located in limestone just above the greenstone-limestone contact on a small southwestward projecting spur or angle of the limestone cliff. South of it and nearly 200 feet below is the glacier in which Jumbo Creek heads and which must be crossed to reach the ore body. The Jumbo and Bonanza ore bodies are at practically the same elevation above sea level, approximately 6,000 feet.

The limestone at the Jumbo is made up near the base of slightly cherty beds ranging in thickness from 8 to 12 inches. The strike is N. 65° W., the dip 35° N. A tunnel 12 feet long was started on the south face of the ridge, 10 feet above the greenstone. The limestone is jointed or cut by minor faults parallel to the bedding and is crossed by veins of calcite from 1 to 2 inches thick. Thin veins of chalcocite and azurite accompany them and fill some of the fractures. Seven feet above the tunnel mouth is the east end of a large chalcocite mass which is well exposed on the axis of the ridge. As indicated on the surface, this body of ore is a mass of solid chalcocite 30 feet long, 6 feet by 4 feet 6 inches at the west end, and tapering to a diameter of 1 foot at the east end. It appears to be a rudely lenticular or possibly a conical body, but has irregularly shaped protuberances, as may be seen at the west end, where the steep west face or slope of the spur gives a cross section of the ore body. (See fig. 8.)

A little way east of the Jumbo tunnel is a second tunnel in limestone a short distance above the greenstone. The tunnel runs nearly north or slightly to the northeast in limestone that strikes N. 65° W. and dips 25° N. In the tunnel, which is 12 feet long, the limestone is crushed and jointed. Small veins of calcite and azurite up to 2½ inches in thickness fill joint cracks, especially a set of perpendicular minor faults or slip planes running N. 70° W. No chalcocite is exposed in this tunnel, but it is believed that the azurite indicates its former presence. Fifty feet below the tunnel a lenticular vein of chalcocite 3 inches thick at its widest part and 3 feet long was found in the limestone.

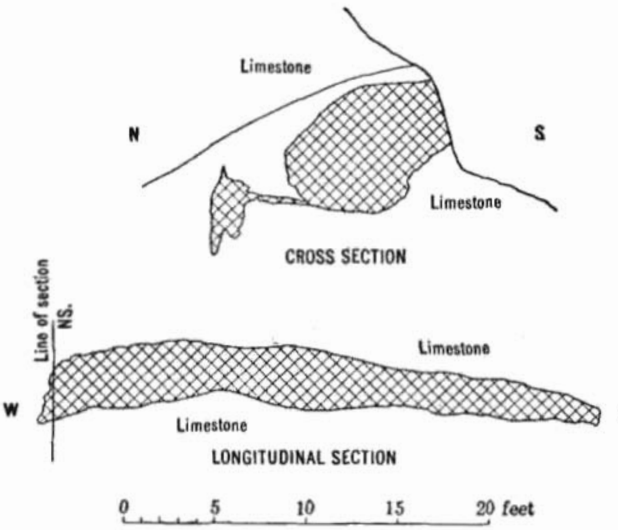


FIGURE 8.—Sketch of the ore body at the Jumbo claim.

ERIE CLAIM.

The Erie claim is the property of the Kennicott Mines Company and is situated on a steep mountain slope near the east side of Kennicott Glacier, 3¾ miles north of Kennicott, at the mouth of National Creek. The discovery point is a little more than 1,000 feet above the nearest point of the glacier and is at the limestone-greenstone contact, which here strikes N. 78° W. and dips 38° N. Between the limestone and the greenstone is a bed of greenish shale of variable thickness, but ranging from 12 to 18 inches. There is also a very thin bed of shale not more than 1 inch thick in the limestone 8 inches above the base. There appears to have been movement between the limestone and the greenstone along their plane of contact, and they were further disturbed by small faults cutting across the contact at high angles to the bedding in such a way that at one place a wedge of greenstone projects into the limestone. The larger shale bed contains many nodules of chalcopyrite from one-half inch to 2 inches in diameter, and with the chalcopyrite there is associated more or less bornite in the larger nodules. Abundant scales of azurite are scattered through the shale. No development work has been done on this claim further than to clear away the débris and make an open cut along the contact so as to expose the copper-bearing shale.

INDEPENDENCE CLAIMS.

The Independence group of claims, belonging to the Kennicott Mines Company, is on the east side of the divide that separates the head of Bonanza Creek from McCarthy Creek and is from 900 to 1,000 feet lower than the saddle where the limestone-greenstone contact crosses the ridge. The copper minerals occur in small veins that contain considerable calcite and belong to a sheeted zone striking N. 38° E., thus crossing the contact almost at right angles. This zone passes from the greenstone into the limestone and has its greatest width (about 50 feet) at the contact. The ore is found in the greenstone only and consists essentially of chalcocite, which fills fractures and is disseminated through the greenstone. It is later than the calcite filling of the sheeted zone and gradually disappears with increasing distance from the zone of mineralization. The main shear zone intersects a system of quartz-epidote veins striking N. 78° E. and carrying a small amount of bornite. There is a marked similarity between the occurrence of copper sulphides in the greenstone at this locality and at the Bonanza mine, but there is no chalcocite body in the limestone of the Independence claim.

MARVELLOUS AND BONANZA EXTENSION CLAIMS.

The shear zone in which the Bonanza ore was deposited extends in a direction about N. 30° E. from the Bonanza mine for a distance of more than a mile. It crosses the saddle between Bonanza Creek and the glacier on the north and extends to the high point of the ridge running northeast from Bonanza Peak. It was not traced beyond that point. There is no evidence of displacement, but there is a shear zone of indefinite width made up of innumerable small parallel fractures filled with calcite and crossed by minor fault planes. These fault planes are believed to have had an important and perhaps a controlling influence in the deposition of copper.

All the Bonanza fault northeast of the Bonanza property is owned by the Mother Lode Copper Mines Company and the Houghton Alaska Exploration Company. The principal exposures of copper minerals are on the Marvellous claim, where a number of short tunnels have been driven. The Marvellous claim is on the north side of the glacier east of Bonanza Peak and is about 2,800 feet above the valley of McCarthy Creek.

At the south tunnel of the Marvellous the limestone is cut by numerous closely spaced parallel joint or shear planes, many of which are filled with calcite and are conspicuous because they are lighter in color than the surrounding limestone. They strike N. 70° E. and dip 70° to 80° N. The tunnel is 15 feet under cover and exposes a vein of chalcocite from 3 to 6 inches wide striking N. 60° W. About 30 feet north of the tunnel's mouth and 25 feet lower is a vein of chalcocite in calcite that reaches a maximum thickness of 9 inches. It strikes N. 60° E. and dips 60° to 65° W. The vein is in a well-defined fault plane and can be traced for nearly 200 feet from the tunnel's mouth. In places it pinches to a thickness of 1 inch and carries no ore. Fine specimens of covellite in chalcocite were obtained from this locality. There is a second parallel vein 12 feet to the north, but it is not so long.

The main tunnel of the Marvellous is 300 feet northeast of the south tunnel and runs 100 feet S. 85° W. in dark-gray limestone. The vein is a stockwork of small calcite veins, with chalcocite and azurite in crushed limestone. About 20 feet from the face is a crosscut 9 feet long where there is a vertical fissure in the limestone striking N. 25° E. The fissure is filled with calcite and carries chalcocite and azurite. It has a thickness of 6 inches. The limestone is much discolored by iron oxide. Above the tunnel is a large mass of azurite formed by the oxidation of chalcocite whose downward extension the tunnel was expected to strike.

A third tunnel, called the north tunnel, was started on the Marvellous claim 200 feet northeast of the main tunnel and 100 feet above it. The copper minerals at this exposure occur along bedding planes of the limestone, which here strikes N. 40° W. and dips 35° E., and along fault planes that cross the bedding. The faults strike N. 10° W. and dip 44° E.

NIKOLAI CLAIM.

The Nikolai claim is located near the head of Nikolai Creek, 3¾ miles northeast of the junction of Nikolai and McCarthy creeks and 2,150 feet above it. The exposed ore body is situated near the top of the greenstone formation, about 150 feet below the base of the limestone, and is associated with a fault which cuts the limestone-greenstone contact at this place. It is composed mainly of chalcopyrite and bornite stained with oxidation products.

An examination of figure 9 will show the relation of the ore body to the associated formations. It will be seen that the limestone and greenstone beds, which here strike N. 60° W. and dip 30° NE., are cut by a fault running N. 50° E. and dipping vertically or high southeast. This fault makes an offset of 300 feet in the limestone-greenstone contact and has produced a vertical displacement of the beds amounting to 150 feet. The course that it follows in the limestone or in the greenstone at a distance from the contact is difficult to trace, but the position of Nikolai Creek east of the Nikolai mine was probably determined partly by the fault, as was also the depression between the small knob on the south side of the Nikolai ore body and the hill slope still farther south. Open spaces between the limestone and the greenstone along the fault plane were filled with masses of coarse white calcite. This filling, however, was not seen where both walls of the fault are limestone or greenstone.

The main Nikolai vein makes a slight angle with the principal fault and lies to the north of it. It strikes N. 55° E. and dips 70° SE. The ore body was produced by deposition and replacement in a shear zone in the greenstone that has a width ranging on the sur-

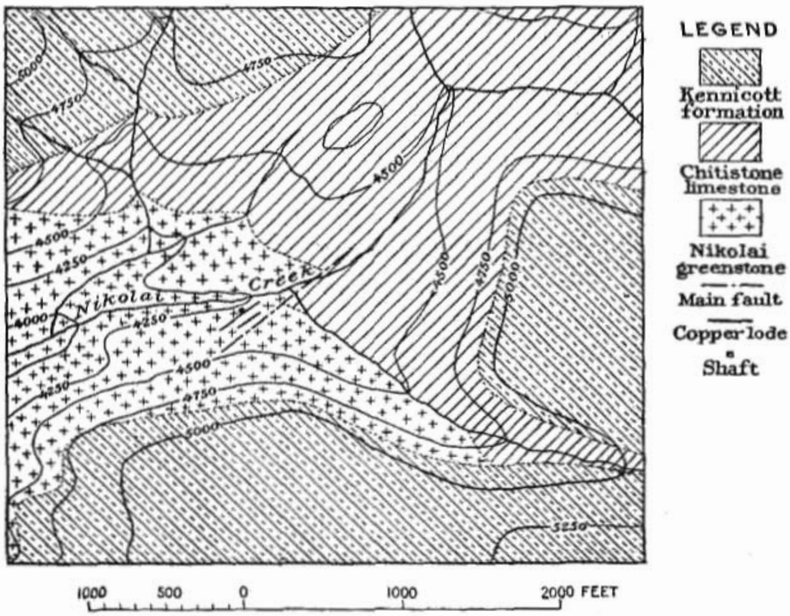


FIGURE 9.—Sketch map of area in vicinity of Nikolai mine.

face from 4 to 6 feet. Deposition of copper minerals was confined to a part of the shear zone that has a horizontal extent from northeast to southwest of 150 feet, but the shear zone itself can be traced 100 feet farther southwest and 350 feet farther northeast, making a total exposure of 600 feet.

Several open cuts were made on the vein and a shaft was sunk in the ore body near its northern end a few feet above the creek. Fifty feet south of the shaft two open cuts expose a second fault zone parallel to the first, along which copper minerals were deposited. It was traced for a distance of 50 feet on the surface. Moss and loose rock hide it beyond these limits, but it evidently is much more poorly developed than the fault zone to the north.

Another set of fractures or joints, with strike N. 15° W. and dip 70° W., is associated with the northeast-southwest faulting but does not appear to have resulted in any important displacement or to have offered favorable channels for circulating mineral solutions, although the openings near the main vein were followed. Still other fractures are present which were not recognized as belonging to any definite system.

The copper minerals that form the Nikolai ore body occur partly as a filling in preexisting cavities and partly as a replacement of greenstone near the cavities. The principal copper mineral is chalcopyrite, but with the chalcopyrite is associated considerable bornite. Where the copper minerals were deposited in cavities they are associated with other minerals—calcite, epidote, and quartz; where they replace greenstone the other minerals, if they can be distinguished at all, are less in evidence.

Deposition was greatest within the sheared and broken rocks of the fault zone, doubtless because the opportunity for circulation was best there. The greenstone walls, within a foot or so of the fault, are sheeted with innumerable tiny parallel fractures now filled with chalcopyrite, giving the rock a banded appearance. Deposition, however, was not confined to these veinlets. It took place also by replacement of the rock itself, so that the greenstone between the veinlets is impregnated with copper sulphide. Small veins from one-fourth to one-half an inch thick show a banding of minerals in places and give a clue to the order in which the minerals were deposited. The greenstone walls are covered by a multitude of small epidote crystals, with occasional crystals of quartz, and after them calcite was deposited. Grains and small lumps of chalcopyrite are scattered through both calcite and epidote. The ore taken from the shaft consists largely of chalcopyrite, and the dump shows that there is considerable calcite and quartz associated with it. Bornite decreases—a fact that is taken as evidence that this mineral belongs to the upper enriched part of the vein and that the ore will be found to consist of chalcopyrite as depth is gained. There has been some movement along the fault since the ore was deposited, but it probably has not produced much displacement.

WESTOVER CLAIM.

The Westover claim, which is owned by the Alaska United Exploration Company, is on the east side of Bowlder Creek, a little less than 2 miles north of the junction of Bowlder and Dan creeks. The discovery outcrop is a mass of bornite 3,500 feet above the flats of Nizina River and about 375 feet above the glacier moraine of Bowlder Creek valley. It is situated at the contact of the Chitistone

GOLD.

PRODUCTION.

All the gold produced in the Chitina Valley has come from the placers of Dan, Chititu, and Young creeks. Chititu Creek is the principal producer, and after it comes Dan Creek. Young Creek has had only a small output up to the present time and may almost be disregarded as a contributor in past years, but with lower freight rates and cheapened cost of production it may become of greater importance in the future. The total gold production of Chititu and Dan creeks from 1903 to 1909, inclusive, may be estimated with a considerable degree of accuracy as between $450,000 and $500,000, or an average of about $65,000 a year. There is good reason to believe that with the installation of new equipment on the completion of the railroad this yearly average will be much increased.

SOURCE OF THE GOLD.

It may be said with certainty that the source of the placer gold of Dan, Chititu, and Young creeks is in the black shales of the Kennicott formation. This is clearly shown by the distribution of the gold itself. All the tributaries that flow into Dan and Copper creeks from the northeast, including Dan Creek above the mouth of Copper Creek, lie within the limestone-greenstone area and carry no gold. All the tributaries that flow into Dan and Copper creeks from the southwest head in the shale area and all carry gold. All the gravel deposits of Dan and Copper creeks except a part of the bench and stream gravels on lower Dan Creek are derived from sources within the drainage basin of these streams. No foreign material was found, and there is almost no possibility that any could be present, for the whole basin is surrounded by steep walls which probably never were below the surface of the ice fields during the time of greatest glaciation.

All the tributaries of Chititu Creek originate within the black shale area and all carry gold, but here, as on Young Creek, part of the gravels are of foreign origin brought in by glacial transportation. Rex Creek is the one exception to this statement, for its gravels, save in the lower mile of its course, are all derived from within its own drainage basin. The gravels of the upper Rex Creek valley are derived from the black-shale area and carry gold. No evidence was obtained to indicate any other source for the gold of Chititu and Dan creeks than the shales lying between Dan and Young creeks, although all the copper and probably all or nearly all the silver of Chititu Creek came from an outside source.

Many small quartz veins carrying pyrite and native gold have been found in the black Kennicott shales between Copper and Rex creeks.

They range in thickness from less than an inch to several inches and are believed to have a close relation to the porphyritic intrusions in the shales. Molybdenite is present and stibnite is also reported from these veins. The placer gravels contain, besides the metals gold, silver, and copper, such heavy minerals as galena, cinnabar, barite, pyrite, and possibly marcasite. Native lead with a white coating, thought to be cerusite, was found in the sluice boxes on Chititu Creek, but may have been introduced by white men or natives, for bullets and shot are common. Not all of these minerals have been found in place in the rock, but it is probable that they also are associated with the quartz veins and porphyry intrusions. Thin veins no thicker than a sheet of paper are common in joint planes of the hard argillite bowlders in the stream gravels. They contain quartz, pyrite, and in places free gold. A thin vein less than one-fourth of an inch thick was found in a porphyry dike on the upper part of Rex Creek, which consisted of quartz with molybdenite and pyrite and assayed 0.18 ounce gold and 12.80 ounces silver to the ton. The dike rock near the vein, although seemingly little altered, contained pyrite and showed a trace of both gold and silver. There is thus good evidence for the source of the gold aside from that furnished by its distribution in the gravels.

The gold in the stream gravels is in part a concentration from the bench gravels through which the streams have cut their channels and in part a concentration from the products of weathering derived directly from the shales and the auriferous veins. Probably the greater part is a reconcentration from the older deposits. Extensive accumulations of high bench gravels are present on both Dan and Chititu creeks. They are best developed on the lower parts of the streams but extend into some of the tributary valleys. The bench gravels of Dan Creek extend west from the neighborhood of Copper Creek and around to the west slope of Williams Peak,[a] where they reach an elevation of over 1,200 feet above the flats of Nizina River. The bench gravels of Chititu Creek reach an elevation as great as or greater than those of Dan Creek. In both places they represent a filling in old valleys through which the present streams have cut their channels and in so doing have reconcentrated a great volume of older deposits, derived partly from the upper Nizina Valley and the region east of the heads of White and Young creeks but chiefly from the drainage basin of Dan and Chititu creeks. When the bench gravels were laid down the two great ice streams that came down the Nizina and Chitina valleys were still in existence, although on the retreat. They formed the barrier behind which it was possible for such deposits to accumulate

[a] Williams Peak is named in honor of John M. Williams, a pioneer prospector of the Nizina district, who was killed in a snowslide on Bonanza Creek on April 7, 1909.

and brought to the bench gravels that part of them which is foreign to Dan and Chititu creeks. It is impossible to say what proportion of the gravels consists of foreign material, but it is believed to be the smaller part. Some of the bench gravels carry gold in sufficient quantity to be of commercial importance, as has been proved at a number of places. A reconcentration of such deposits accounts in part for the greater richness of the stream gravels. The process that brought about this concentration is exactly the same in principle as that carried on in the miners' sluice boxes on a much smaller scale but in a much shorter time. This concentration is probably slower at present than it was before the streams had cut through the deep gravel accumulations and intrenched themselves in the underlying hard rock, but it still goes on, for erosion of the bench gravels has not ended.

PLACER DEPOSITS.

DAN CREEK.

Dan and Copper creeks may well be regarded as one stream in spite of whatever accident or design resulted in their having different names and of the fact that the upper part of Dan Creek sometimes carries as much or more water than Copper Creek. A reference to the geologic map (Pl. III, in pocket) will show that the two streams follow closely the course of the fault that gave the older greenstone and the limestone on the north their relative elevation above the base of the Kennicott formation. With unimportant exceptions, the north side of the Dan and Copper creek valleys is in limestone and greenstone, the south side in shales of the Kennicott formation. Most of Copper Creek is in a broad glaciated valley, but at a point nearly 1 mile above its mouth the creek enters a narrow rock-walled canyon that opens slightly below Copper Creek yet extends down Dan Creek nearly a mile. Dan Creek valley below the canyon is narrow and shut in by steep mountains as far as the flats of Nizina River.

During the ice invasion the Copper Creek valley was swept clear of whatever unconsolidated deposits may have accumulated, and the form of the valley was considerably modified. When the ice was retreating some glacial débris was left on the valley floor, but it is of less importance in connection with the gold placers than the accumulations of stream gravels that have been laid down since the glacier disappeared. In this respect the placers of Copper Creek are different from those of Dan Creek.

All the tributaries of Copper Creek on its south side, as Idaho, Rader, and Seattle gulches, carry gold, but most of the output of the creek comes from near the mouth of Rader Gulch. Part of the gold is from the gulch itself and part is from Copper Creek, just below the gulch. The gravels are all shallow. Those in the mouths of the gulches are composed almost entirely of shale, chiefly from the Kennicott formation but also in part from the McCarthy shale. They occupy narrow gulches and accumulate so rapidly that the streams have difficulty in removing them. The gravel deposits of Rader Gulch are of this character. They consist of loose shale fragments and occupy only a few hundred feet of the lower end of the gulch, for above them the grade is so high and the channel so narrow that the water removes loose material rapidly. The gravels of the main stream contain material from all the formations within the drainage basin. At Rader Gulch they form a narrow flood-plain area between the mountain slope on the southwest and a low ridge on the northeast. They contain considerable coarse material mingled with blocks and bowlders of glacial origin and much fine material derived from the shales. The gold is not a concentration from older, lower-grade deposits but is derived directly by weathering and by stream concentration of the products of weathering. The source of most of the gold is clearly indicated by its position in the gravels at and just below the mouth of Rader Gulch and the presence of workable gravels on the lower part of Rader Gulch.

Idaho and Seattle gulches resemble Rader Gulch in their form and the character of their gravel deposits, but they have not been found to carry as much gold.

Copper Creek is difficult to reach with supplies except in winter, for the canyon makes necessary a high climb of more than 1,000 feet around the side of Williams Peak. Men on foot, however, can follow the creek. Logs have been placed across the stream in the canyon and make it possible to avoid bad places. Mining on Copper Creek is done with pick and shovel. There is a small supply of timber for firewood and for sluice boxes, but it would not be adequate for extensive mining operations. Good timber for lumber can be secured along Nizina River, but the expense of carrying it to Copper Creek under present conditions, except in winter, would be great.

The gold of Dan Creek has a less simple history than that of Copper Creek. It is in part a reconcentration from older gold-bearing bench gravels and in part, like that of Copper Creek, a concentration from the products of later erosion. Old high-bench gravels are found on both sides of Dan Creek, especially on the lower part, but near the west end of the canyon they lose their prominence and disappear altogether at or below the mouth of Copper Creek. Dan Creek has cut its present channel down through this great accumulation of glacial and stream deposits and into the shales beneath. The stream gravels consist of greenstone, limestone, and shale. They form between rock walls a narrow flood plain overgrown with timber and in many places of less width than a placer claim. A large part of the gravels consists of bowlders ranging from cobbles to masses several feet in diameter. Most of them, however, are not too large to be moved by hand. All the fragments are rounded. They were deposited by a rapidly flowing current and the bedding is poor. Buried spruce logs and fragments of wood are common. The gravel and its slight covering of soil range from 8 to 12 feet in depth.

Dan Creek gold is coarse and smooth and is accompanied by silver and copper. It has been concentrated on bed rock or within the lower 2 feet of the gravel. A large proportion, however, finds its way into the cracks and crevices in the shale, so that in places a foot or more of the shale has to be removed to recover all the metal. An unusual feature of the gravels of Dan Creek is the small quantity of fine gold found in them. Very little fine gold is recovered in the sluice boxes and practically none is found in panning. Numerous prospect holes show that the gold is well distributed across the channel and have failed to discover the presence of a concentration into a defined pay streak. Beside the holes sunk on the flood plain, tunnels have been driven along bed rock at the base of the bench gravels above the present flood plain. The depth to which the creek has incised itself in the shales is not constant but is rarely less than 10 or 15 feet. Thus the base of the bench gravels or the "rim" of the channel stands well above the creek. The tunnels driven in the bench gravels show the presence of gold in sufficient amount to be of commercial importance and in several places in sufficient amount to pay for extraction under the expensive methods necessary in prospecting the gravels, but the final test of value will come when an attempt is made to extract the gold on a large scale.

An old channel formerly occupied by Dan Creek lies in the bench gravels on the south side of the present stream. It runs on the south side of the small round hill west of the mouth of Copper Creek and follows the hillside to the west, but it has not been traced definitely. Doubtless much of it has been removed by erosion. Its gravels carry gold, and an attempt has been made to exploit them in a small way, but without great success.

Dan Creek is favorably situated with reference to timber for mining purposes and has a good supply of water. It is reached without any difficulty from the Nizina, and a wagon road for hauling timber and supplies has already been built. All mining to the present time has been by the simplest methods. The one employed for several years is to undercut the bank with a stream of water and by washing away the gravel to leave the gold. Bowlders and small rocks are piled parallel with the bank and only a few feet from it. Then water controlled by dam and gates is turned in and forced against the bank, undercutting it and carrying away most of the fine gravel. The large rocks are piled back by hand and the remaining fine gravel and gold are shoveled into sluice boxes, after which bed rock is cleaned. Preparation has been made for installing a hydraulic plant on Dan Creek, and it will be put in place as soon as the railroad is completed and better facilities for carrying freight are established.

CHITITU CREEK.

Chititu Creek and its two branches, Rex and White creeks, lie wholly within the area of Kennicott sediments. These streams, like Dan Creek, have cut their present channels through the old valley filling and entrenched themselves in the black shales. The amount of this entrenchment is variable, ranging from nothing below the canyon on Chititu Creek to 60 or 70 feet on White Creek, but the increase is not uniform. It is about 30 feet at the mouth of White Creek, but is greater than that in places farther down on Chititu Creek. It decreases as Rex Creek is ascended and also on the head of White Creek. The canyon on Chititu Creek is due to the presence of a large porphyry dike in the black shales, which has protected them from rapid stream cutting and confined the water to a narrow channel. The canyon is small but marks the downstream limit of gold-bearing gravels that are now considered of commercial importance.

Above the rim of the shallow trench cut in the shales by the stream are steep banks of rudely assorted gravels. The top of the gravel bluff at Sunday Gulch is a little more than 500 feet above Chititu Creek. Half a mile downstream the top of the bluff is 750 feet above the creek, but from this point on the difference grows smaller till the bench gravels merge into the gravels of Nizina Valley a short distance below the canyon. Bench gravels are prominent on Rex Creek for a mile or more above its mouth, but they either were not deposited or have been removed from the upper end of the creek, where the unconsolidated accumulations are wholly glacial débris. A large part of the bench deposits of White Creek have been eroded away, yet they extend up the creek in conspicuous exposures for at least 2 miles.

The richest gold-producing gravels of Chititu Creek are the stream gravels; they include all of Chititu Creek above the canyon, together with a large part of Rex and White creeks. The most important parts of these creeks, viewed from the standpoint of gold production, are represented on the sketch map (fig. 10). The stream gravels cover the floor of the shallow rock-rimmed trench to a depth of 8 to 16 feet, depending partly on the form of the bed-rock surface and partly on the irregularities of deposition by a swiftly flowing current. They form a flat, originally covered with timber and underbrush, ranging in width from 200 to 700 feet. The gravels of Chititu and White creeks and of the lower part of Red Creek consist of shale, limestone, sandstone, and quartz diorite porphyry, all of local origin, mingled with greenstone, diorite, and other rocks brought in by glacial ice from a foreign source. Shale, sandstone, and porphyry make up the fragmental deposits of the upper part of Rex Creek.

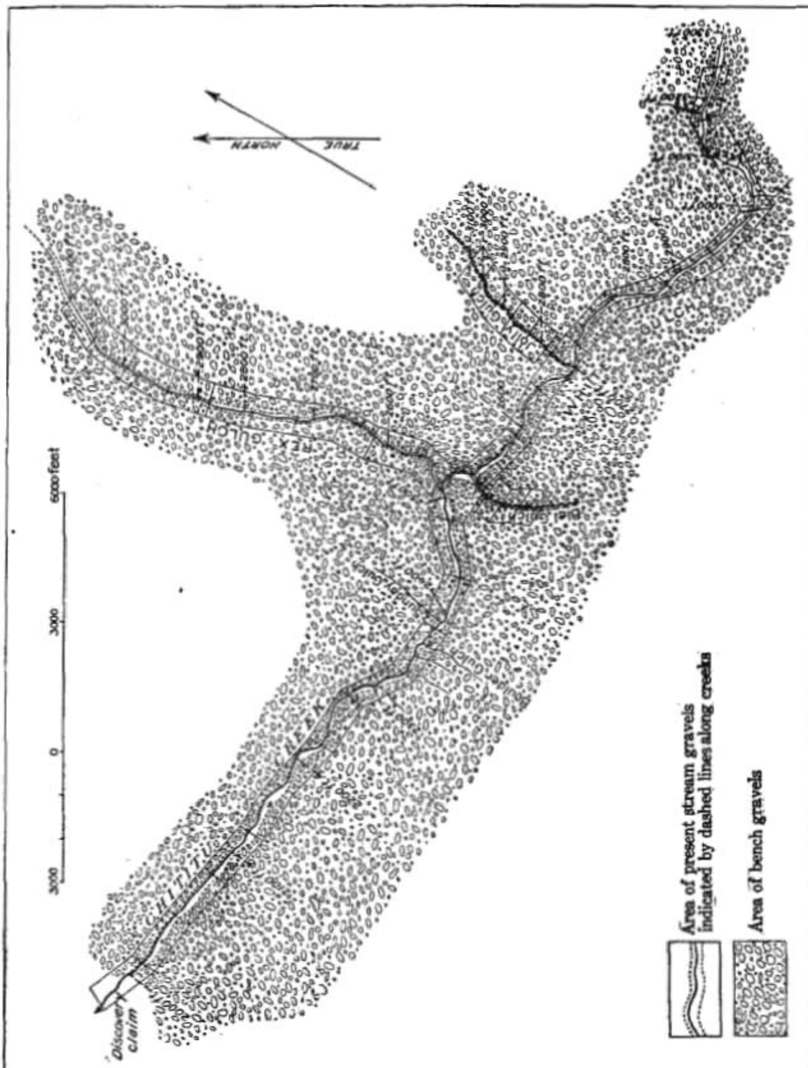


FIGURE 10.—Sketch map of a part of Chititu, Rex, and White creeks, showing the location of claims and the relation of bench and stream gravels.

Bowlders and large blocks make up a considerable portion of the gravel deposits, but not so large a proportion as on Dan Creek. Some of the glacial erratics are 6 or 8 feet in diameter. Most of the bowlders, however, can be sent through the sluice boxes, although it is necessary to break part of them with powder.

The gravels producing gold at present include those of Chititu Creek and of the lower part of Rex Creek. Very little work aside from that necessary to hold the claims has been done on White Creek for several years. In a general way the gold of Chititu Creek is distributed through the gravel from rim to rim of the rock channel, but it was found that at one place near the canyon there is a very well-defined pay streak, such as had not been found before on any of the claims farther up the creek. Most of the gold is on or near bed rock. Very little of it is found in the upper part of the gravel. The gold penetrates the bed rock through cracks and all openings, so that it is necessary to clean the rock carefully by hand after taking up the loose upper part to the depth of a foot or more. There are considerable differences in the character of the bed-rock surface, owing to irregularities in form and differences of hardness. In places the old stream has worn the rock smooth or has hollowed out cavities and depressions. Differences in the depth of weathering also add to the irregularities of the exposed surface, for the streams of water from the hydraulic giants cut away the loose rock and leave the harder parts standing in relief. Without doubt much of the gold of Chititu, Rex, and White creeks is a concentrated product from the bench gravels and the remainder is derived directly by weathering from the surrounding shales. All the bench gravels carry gold in some amount, and with decreased cost of mining it is probable that some of them will be exploited.

Chititu gold is finer and less worn than that of Dan Creek. It was found on the lower part of Chititu Creek that in a set of 4 screens ranging from 10 to 20 mesh about equal amounts of gold, by weight, were caught in each screen; at the mouth of Rex Creek it was estimated that from 25 to 40 per cent of the gold passes through a 16-mesh sieve. These results are in marked contrast with the heavy coarse gold of Dan Creek, yet both come from the same area of mineralization. There is, nevertheless, a little coarse gold on Chititu Creek, and several large nuggets have been found. The gold assays about $18.70 per ounce when cleaned. A large quantity of copper is obtained in the clean-up, and nuggets of native silver are common. Several other heavy minerals besides copper and silver are caught in the sluice boxes, such as pyrite, galena, stibnite, barite, and lead. Most of the lead was evidently introduced through the use of firearms, but some of the pieces examined did not resemble the battered bullets found in the sluice boxes and had a thick white coating of oxidized material. One of the largest of the native-silver nuggets was found in 1909; it weighed over 7 pounds but contained considerable quartz.

Native copper is a source of considerable difficulty and expense in mining. Several hundred pounds of fine copper are secured at every clean up and many large masses are taken from the cuts. Occasionally a large piece goes through the boxes and into the dump, but the largest are too heavy to be driven out of the cut by the giant. All the gold is picked over by hand to remove the fine copper not separated in the sluice box. During the early days of mining no effort was made to save the copper, since the expense of carrying it to the coast was greater than its value, yet with railroad transportation it should now be worth considering.

For the first few years after the discovery of gold on Chititu Creek mining was conducted on Rex and White creeks as well as on Chititu Creek. Rich ground was found on all these streams, and the principal operations were on the upper half of Chititu Creek, the lower end of Rex Creek, and the upper part of White Creek. All the work was done by hand and attention was directed to the richest ground only. At present two hydraulic plants are in operation, one on Chititu Creek and the other at the mouth of Rex Creek. Most of the claims on Chititu Creek are owned by the Nizina Mines Company and a complete hydraulic plant has been installed to exploit

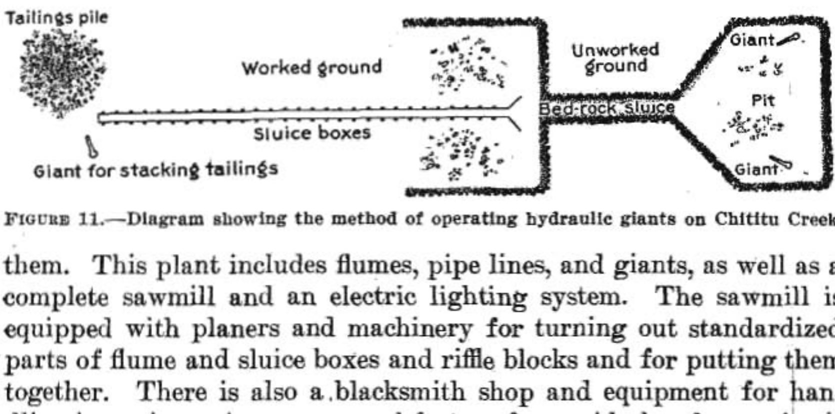


FIGURE 11.—Diagram showing the method of operating hydraulic giants on Chititu Creek.

them. This plant includes flumes, pipe lines, and giants, as well as a complete sawmill and an electric lighting system. The sawmill is equipped with planers and machinery for turning out standardized parts of flume and sluice boxes and riffle blocks and for putting them together. There is also a blacksmith shop and equipment for handling iron pipe. A very unusual feature for an Alaska placer mine is the complete system of accounting by which all expenses are charged in their proper place and the cost of any part of the operations is made known.

The method of handling gravel in the pit is shown in figure 11. When the sluice boxes have been put in place a bed-rock flume is carried upstream in the gravels as far as desired. Then the upper end of this cut is widened to 100 or 150 feet and a giant is placed on either side so as to drive the gravel along the sloping face into the head of the flume. By this method the force of the giants is added to the ground sluice water and a decided gain in efficiency is obtained over the former method of working against the face with the giants turned upstream and away from the sluice boxes. In practice only one giant is used at a time, the opportunity thus being given for a gang of men to remove the large bowlders on the opposite side. A giant is also required at the lower end of the sluice boxes to stack the tailings and keep the end of the boxes clear.

Mining operations at the mouth of Rex Creek have been conducted by Frank Kernan with a smaller plant than that on Chititu Creek, but they have been carried on for a longer time. A small giant is used and water is brought from Rex Creek in a flume. The conditions here are about the same as on Chititu Creek, but the width of gravel between the rock rims is less. Some very rich ground has been found on the lower end of Rex Creek and just below that on Chititu Creek.

The canyon of Chititu Creek is 4½ miles from the flats of Nizina River, and the character of the country is such that a good wagon road could be constructed at moderate expense. Such a road in connection with a bridge over the Nizina River would make communication with the railroad at Kennicott River easy and would be of great advantage to the miners of Chititu Creek, since it would enable them to secure supplies at any time of the year at a reasonable cost. It would also do much to solve the problem of securing labor at the time when it is most needed and thus prevent the necessity of carrying a large force of men on the pay roll during the whole season. Labor is a large item in the expense of operation at present chiefly because of the large amount of time spent in winter freighting. Wages range from $90 per month and board to $5 per day, with an additional amount to foremen.

Chititu Creek has a sufficient volume of water for all the demands that are made on it by the hydraulic plant in operation. The supply on Rex and White creeks is naturally less and probably would be inadequate for a large plant at some seasons of the year. Chititu Creek has a fall of 180 feet per mile from the forks to the canyon. Rex and White creeks have a fall of 250 feet per mile in the lower 2 miles of their courses. Thus a good head of water can be secured on each of these streams. There is an abundance of good timber for lumber and mining purposes on Chititu Creek below the canyon.

YOUNG CREEK.

Young Creek resembles Dan and Chititu creeks in having cut its channel through an old gravel filling in a glaciated valley. The present stream flows in a trench cut in black shales and lies from 20 to 40 feet below the base of the bench gravels. Its channel is in reality a shallow canyon whose walls are shale at the base and gravel above. Young Creek valley was once occupied by a glacier which came into it across a broad low divide near its head and was an overflow branch of the great Nizina Glacier. The gravels of Young Creek therefore contain a large amount of foreign material from the upper Chitina Valley in addition to rocks of the Kennicott formation and the greenstone from its own valley.

A large part of the creek has been staked for placer gold, although the production has not yet been enough to give much encouragement for mining. Two men were prospecting on the lower part of the stream in 1909. In previous years work was done on Calamity Gulch also, but the results were not sufficiently favorable to lead to its continuation.

Young Creek carries a large stream of water at all seasons of the year and has an average fall of 100 feet per mile above the Nizina flats. It is difficult to reach the upper part of the creek because of the canyon-like character of the stream channel and of the absence of trails above the creek on the hill slopes, and for this reason it is customary to cross the ridge from the head of White Creek and come down on Young Creek at the head of Calamity Gulch. This is the route always followed by prospectors bound for the head of Young Creek.

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