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THE KOTSINA-KUSKULANA DISTRICT ALASKA

BY

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AND

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PREFACE.

By Alfred H. Brooks.

Topographic and geologic reconnaissance surveys of the Kotsina-Chitina copper belt, Alaska, were completed by the United States Geological Survey some 20 years ago. Surveys of this character determine the general distribution and geologic occurrence of mineral deposits. They do not, however, yield the detailed facts on the geology of the mineral deposits necessary to the mining engineer who is charged with the duty of determining the commercial possibilities of development. In the case of copper deposits it is particularly desirable to have full geologic information before installing the large plants that are necessary to mine and concentrate copper ores. It is the purpose of the Geological Survey to examine and map in detail all the Alaskan copper-bearing districts which give promise of yielding commercial ores. This plan is being carried out as rapidly as the funds available will permit, and the present report is one of the results of this plan.

It is unfortunate that, owing to the interruption caused in Mr. Moffit's and Mr. Mertie's Alaska work by their assignment to war duties, the completion of this report has been long delayed. This volume not only contains a complete analysis of the economic problems relating to the ore deposits of the district but is a noteworthy contribution to knowledge of its geology. It also becomes the medium of publication of D. C. Witherspoon's topographic map of the district, which most admirably pictures the surface relief.

THE KOTSINA-KUSKULANA DISTRICT, ALASKA.

By FRED H. MOFFIT and J. B. MERTIE, Jr.

INTRODUCTION.

By F. H. MOFFIT.

LOCATION AND AREA.

The Kotsina-Kuskulana district is in the part of Alaska known as the Copper River region. It lies at the west end of Chitina Valley, on the southwest slope of the Wrangell Mountains. (See Pl. I, p. 2.) The district owes its present importance to the possibility of its becoming a producer of copper and perhaps also of gold and silver.

The area described in this report is about 16 miles long and 12½ miles wide, thus having an area of approximately 200 square miles. Its longer axis extends from northwest to southeast, and its center is near the intersection of parallel 61° 40′ north latitude and meridian 143° 55′ west longitude.

PREVIOUS WORK.

The first account of the Kotsina-Kuskulana district by a representative of the Federal Government was given by Rohn[1] in 1900. Rohn visited upper Kuskulana River in 1899 on his way from the mouth of Chitina River to the Nizina and wrote a brief description of its geography and geology. His trip was an exploratory trip and he could give little attention to details of geology, yet he interpreted the principal geologic features of the district with considerable accuracy and proposed most of the formation names now in use there.

Schrader and Spencer[2] visited the Kotsina-Kuskulana district in 1900, during the course of a geologic reconnaissance survey of the

[1] Rohn, Oscar, A reconnaissance of the Chitina River and the Skolai Mountains, Alaska: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 393–440, 1900.

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

Chitina and Hanagita valleys. At the same time Gerdine and Witherspoon made a topographic map of an area including this district, which, with some corrections, has been in use ever since. The work of Schrader and Spencer greatly increased our knowledge of the areal geology and gave the first official account of such copper deposits as were known at that time.

Mendenhall,[3] the next to visit the district, examined the copper prospects of Kotsina River and Elliott Creek in 1902. He was able to give a more extended account of the Kotsina prospects than Schrader and Spencer and described for the first time the copper deposits of Elliott Creek.

In 1907 Moffit and Maddren[4] examined the copper prospects of the Chitina Valley from Kotsina River to Nizina River and made certain additions and a few corrections to the geologic map prepared by Schrader and Spencer. New prospects had been discovered in the five years from 1902 to 1907, and, although little underground work had been done, numerous open cuts on the many claims gave opportunity to examine the surface exposures, so that with the longer time for study at their disposal they were able to describe the copper deposits of the district in greater detail than the earlier workers.

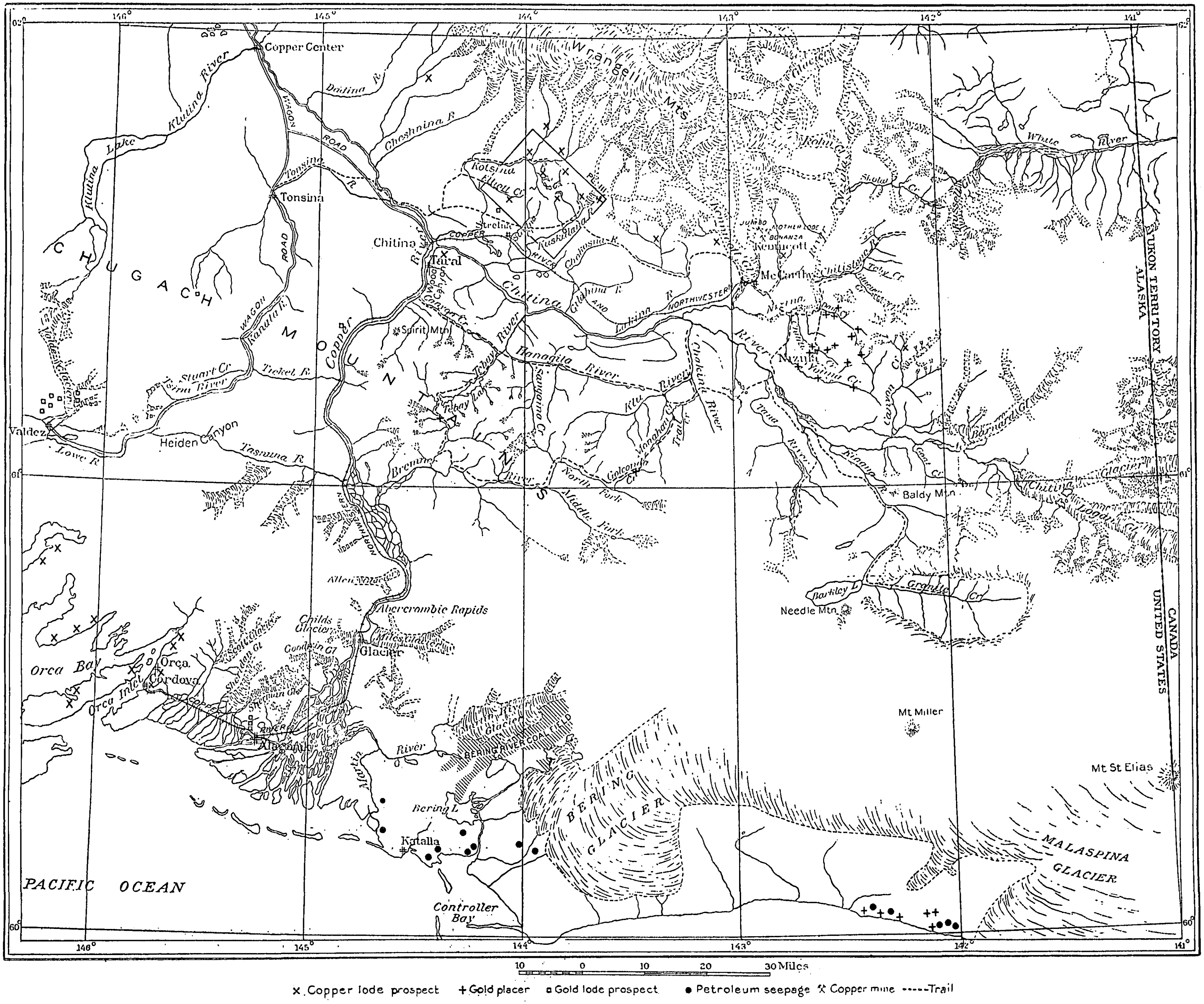
Besides these studies by geologists of the United States Geological Survey there should be mentioned the work of many capable mining engineers who have visited the district from time to time in the interest of capitalists and miners. Their work is not intended for the public, so that their written reports, although containing much valuable information, are not available for general use.

PRESENT INVESTIGATION.

The work that furnishes the material for this report was begun in 1912, when an area that would include as much as possible of the copper-bearing rocks was outlined for topographic mapping and about one-third of the area was surveyed by D. C. Witherspoon. He was accompanied to the field by Theodore Chapin, who started the geologic mapping about the middle of July. In the absence of a suitable topographic base map Mr. Chapin made use of a small plane table and an open-sight alidade in mapping formation boundaries and locating outcrops, transferring Mr. Witherspoon's control points to his own sheet as fast as the position of these points was determined. About the middle of September J. B. Mertie, jr., and the writer also entered the field, having been unable

[3] Mendenhall, W. C., and Schrader, F. C., The mineral resources of the Mount Wrangell district, Alaska: U. S. Geol. Survey Prof. Paper 15, 1903. Mendelhall, W. C., Geology of the central Copper River region, Alaska: U. S. Geol. Survey Prof. Paper 41, 1905.

[4] Moffit, F. H., and Maddren, A. G., Mineral resources of the Kotsina-Chitina region, Alaska: U. S. Geol. Survey Bull. 374, 1909.



MAP OF THE CHITINA AND LOWER COPPER RIVER VALLEYS, SHOWING LOCATION OF KOTSINA-KUSKULANA DISTRICT.

to go sooner because of the delay of Congress in making the annual appropriation for geologic work in Alaska. They were joined by Mr. Chapin and began work in the Strelna Valley, but during the later part of September heavy rains destroyed long stretches of the Copper River & Northwestern Railway, interrupting all traffic and making it impossible to obtain supplies for the men and feed for the horses, so that the party was compelled to leave the field October 1.

Topographic mapping was completed in 1913 (Pl. II, in pocket), but geologic mapping was suspended that year. In 1914 Mr. Mertie and the writer again entered the field to continue the geologic surveys and to study the mineral deposits. They were accompanied by Glenn Connelly, B. C. Palmer, and S. A. Witherspoon, all of whom had had extensive previous experience in Alaska as members of Geological Survey expeditions. The party was supplied with the necessary camp equipment and a pack train of horses. The field season extended from June 10 to October 1. The weather was favorable during most of the season except the later part of August and the early part of September, when fog, rain, and snow interfered seriously with the work. It was hoped that time would be available for a rapid revision of the formation boundaries mapped by Mr. Chapin in 1912, for it was suspected that some adjustment of the plane-table surveys to the finished topographic map would be necessary, but the snows of later September prevented this revision. Parts of the district were revisited in 1916, but before the report describing the work was ready to be printed the United States entered the World War, and it became necessary to postpone publication. Another visit to the Kuskulana Valley was made by the writer in September, 1919, in order to revise the chapters on economic geology, for it was known that considerable development work had been done since 1916.

The writer is indebted to nearly all those living within the boundaries of the area mapped for favors of one kind or another—for information furnished, for hospitality, for the use of cabins, and for many other kindnesses. Special mention, however, should be made of Messrs. V. J. Dwyer, A. G. Elliott, Adolph Ammann, E. F. Gray, Angus MacLeod, Ole Berg, and Angus MacDougall. During an experience in Alaska extending over a considerable number of years the writer has rarely found an Alaskan who did not willingly assist him by every means, even when such assistance involved considerable personal inconvenience. The mining men of the Kotsina-Kuskulana district have furnished no exception to this rule.

The petrographic and related descriptions in this report, together with a part of the description of the metalliferous deposits, were written by Mr. Mertie, who carried on the office petrographic studies. R. M. Overbeck assisted in the study of polished sections of ores.

GEOGRAPHY.

DRAINAGE.

Kotsina and Kuskulana rivers are the principal streams of the district which is here designated by their names. Together with certain of their tributaries they drain all the area mapped (Pl. II, in pocket). The drainage basins of the two rivers include an area of about 500 square miles, a little more than half of which belongs to Kotsina River. It happens also that a little more than half the area under consideration lies within the Kotsina basin. Both rivers are glacial streams, receiving most of their water from melting ice on the south slopes of Mount Wrangell and Mount Blackburn, and therefore show great variation in the quantity of water discharged, dependent on variations in seasonal and daily temperatures.

Kotsina River has two principal branches, the Long Glacier stream, not shown on Plate II, and Kluvesna River. Long Glacier, sometimes known as "the mud glacier," and Kluvesna Glacier descend the slopes of Mount Wrangell. They contribute most of the water in the Kotsina. The several small glaciers that feed the upper Kotsina descend from the ridge connecting Mount Wrangell with Mount Blackburn. Clear Creek is the only clear-water stream of considerable size coming into Kotsina River from the north. All the tributaries from the south, including Elliott Creek, are clear except in very warm weather or in time of heavy rains, yet several of them, such as Peacock, Roaring, Amy, Rock, and Lime creeks, head in small glaciers.

The parts of Kotsina and Kluvesna rivers represented on Plate II flow over broad gravel-covered valley floors shut in by steeply rising mountains. The river flood plain nowhere exceeds half a mile in width, although the low, flat timber-covered benches that border the flood plain increase the width of the valley floor to 1 mile near the junction of Kotsina and Kluvesna rivers. A mile above the mouth of Rock Creek the Kotsina flood plain narrows to about 100 feet where the river runs between two rock benches that form a short canyon. The flood plain again narrows for a short distance at Rock Creek but spreads out immediately below and shows no further pronounced contraction within the area mapped. A short distance below Long Glacier Kotsina River enters a canyon, Pl. IV, p. 6) partly in gravel deposits, partly in hard rock, which gradually becomes narrower and deeper and which continues as far as Copper River, half a mile above the mouth of Chitina River.

A notable feature of Kotsina River that it shares with several other streams of Chitina Valley is its annual flooding due to the sudden release of water impounded by one of the small glaciers of the upper Kotsina. The glacier blocks the lower end of a tributary valley not occupied by ice. During the winter the under-glacier outlet of the stream in this valley is closed by ice, so that the water gradually accumulates, forming a lake held back by the glacier. When the pressure becomes so great that the ice is no longer able to withstand it the water bursts out from beneath the glacier, flooding the Kotsina Valley and strewing it with blocks of ice for several miles below the glacier. The flooding commonly takes place in the later part of July, less commonly early in August. Occasionally the dam persists through the summer and is broken out in winter. Such a time was late in the winter of 1907, when several men who were freighting their summer's supplies over the ice of Kotsina River narrowly escaped losing them. In 1914 the flood began late on July 25 and gradually increased till it was at its height, covering the whole valley floor for a width of half a mile about 11 p. m. July 26. Before noon of July 27 the stream was in normal condition again. Those who have seen it say that the water bursts from beneath the glacier like a great fountain and throws blocks of ice in all directions. One of the most noticeable effects of the flooding is that the stream channels are shifted from one place to another and that immense quantities of gravel are moved downstream.

Kuskulana River heads in Kuskulana Glacier and flows southwestward to Chitina River, which it joins 9 miles above the Copper. Its principal tributaries are Strelna, Clear, Porcupine, and Nugget creeks on the north and Trail and Slatka creeks on the south. The valley of upper Kuskulana River is broad and open. For 5 or 6 miles below the glacier the river runs over the gravel bars of the broad flood plain. Before emerging from its own valley, however, and entering that of Chitina River at a point about 9 miles below Kuskulana Glacier, it flows into a canyon in which it crosses the broad lowland between the mountains and the Chitina. The tributaries of Kuskulana River are clear-water streams. One or two of them have small glaciers at their heads but do not receive enough mud from these glaciers to color the water. Like most of the tributaries of the Kotsina, they are torrential streams flowing in narrow valleys and rocky gulches. Strelna Creek is the largest tributary of the Kuskulana. Its drainage basin occupies the south-central part of the area mapped and gives access by high passes to Elliott, Copper, and Rock creeks of the Kotsina drainage basin.

RELIEF.

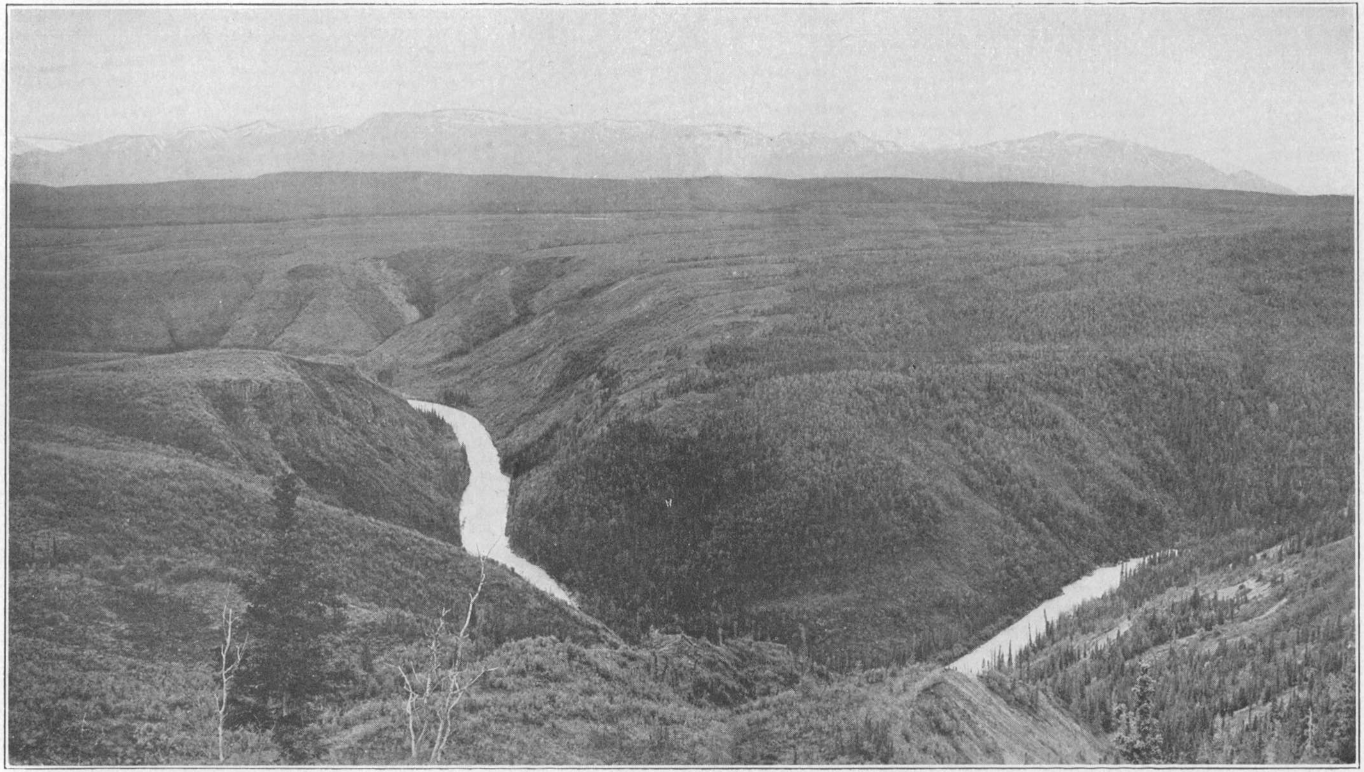
The Kotsina-Kuskulana district lies in the foothills of the Wrangell Mountains, a region of lofty peaks and rugged topography. Mount Wrangell (altitude 14,005 feet) and Mount Blackburn (16,140 feet) stand near by on the north and northeast, the summit of Mount Wrangell (Pl. VI) being only 15 miles from the mouth of Fall Creek on Kluvesna River and that of Mount Blackburn (Pls. V, *A*, and X, *A*) only 11 miles from the head of Kuskulana River. Adjoining the district on the southwest is the broad rolling valley floor of Chitina River, which here, where it joins that of Copper River, has a width of nearly 10 miles. The southwest slopes of the mountains along the border of the district merge into this valley floor and form the valley wall, which sharply delimits the lowland and mountain areas.

The Kotsina-Kuskulana district is occupied entirely by high mountains separated by narrow valleys. The maximum relief of the district as shown by the difference in elevation between Scotty Peak (7,395 feet), at the northern corner, and Kuskulana River (1,600 feet), on the southern border, is 5,795 feet. The valley floors of Kotsina, Kluvesna, and Kuskulana rivers and the margin of the Chitina Valley floor along the southwest border of the district range from 2,000 to 2,500 feet above the sea. Few of the peaks within the district rise with notable prominence above their neighbors, but many of them reach elevations of 5,000 to 6,500 feet. It thus appears that the general relief of the area is from 3,500 to 4,000 feet.

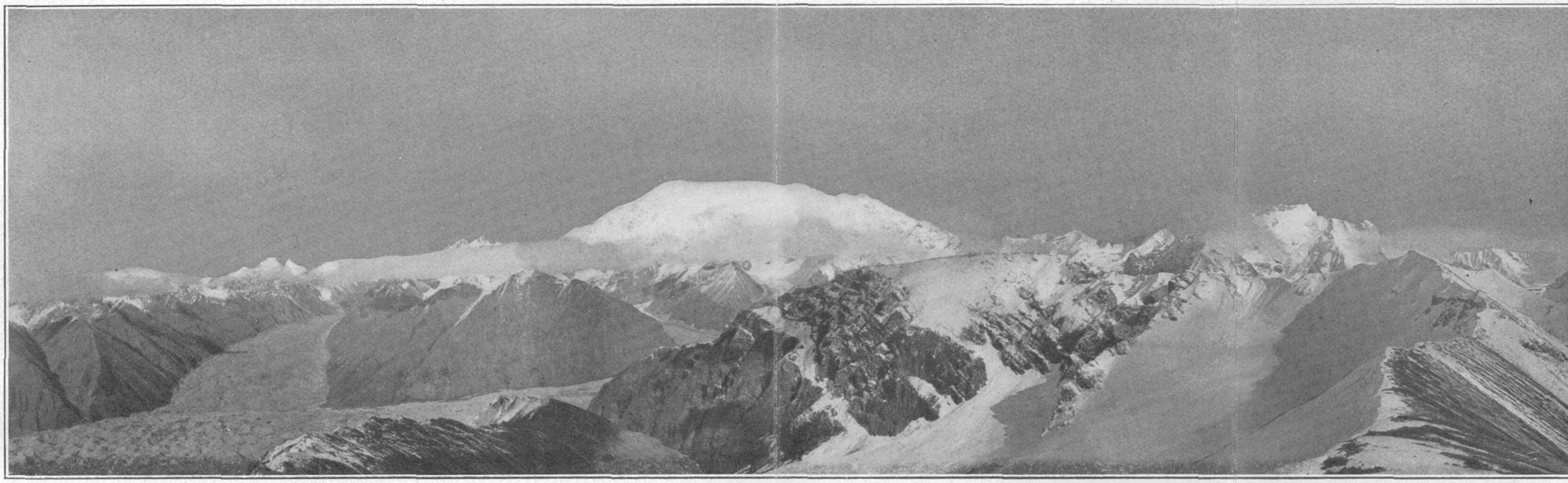
The main valleys, those of Kotsina, Kluvesna, and Kuskulana rivers, were once occupied by large ice streams that formed the trunk glaciers, just as now the streams that flow through these valleys are the trunk streams of the present drainage system. Their walls are steep and straight, for the spurs of the preglacial mountains were truncated, and they show the typical U-shaped cross section of recently glaciated valleys. In places the smoothness of their outlines is modified by gravel benches and other glacial deposits, and everywhere postglacial erosion has begun to destroy the forms produced by glaciation. This is seen most plainly in the narrow rock-walled canyons at the mouths of nearly all the smaller tributary streams (Pl. IX, *A*) and in the steep, narrow gulches on many mountain slopes.

Some of the smaller streams within the district show the same modifications of their preglacial topography as the larger streams. The best examples of this are Elliott, Copper, Rock, Roaring, and Peacock creeks, in the Kotsina drainage basin. Others have steep, narrow V-shaped valleys that undoubtedly were filled with ice at one time but show much less modification by glacial erosion than the larger valleys.

Most of the valleys tributary to the Kotsina and Kuskulana are hanging valleys. Their mouths are above the level of the main valley floors, and they are entered only after a steep climb of several hundred or a thousand feet. Again the most striking examples are



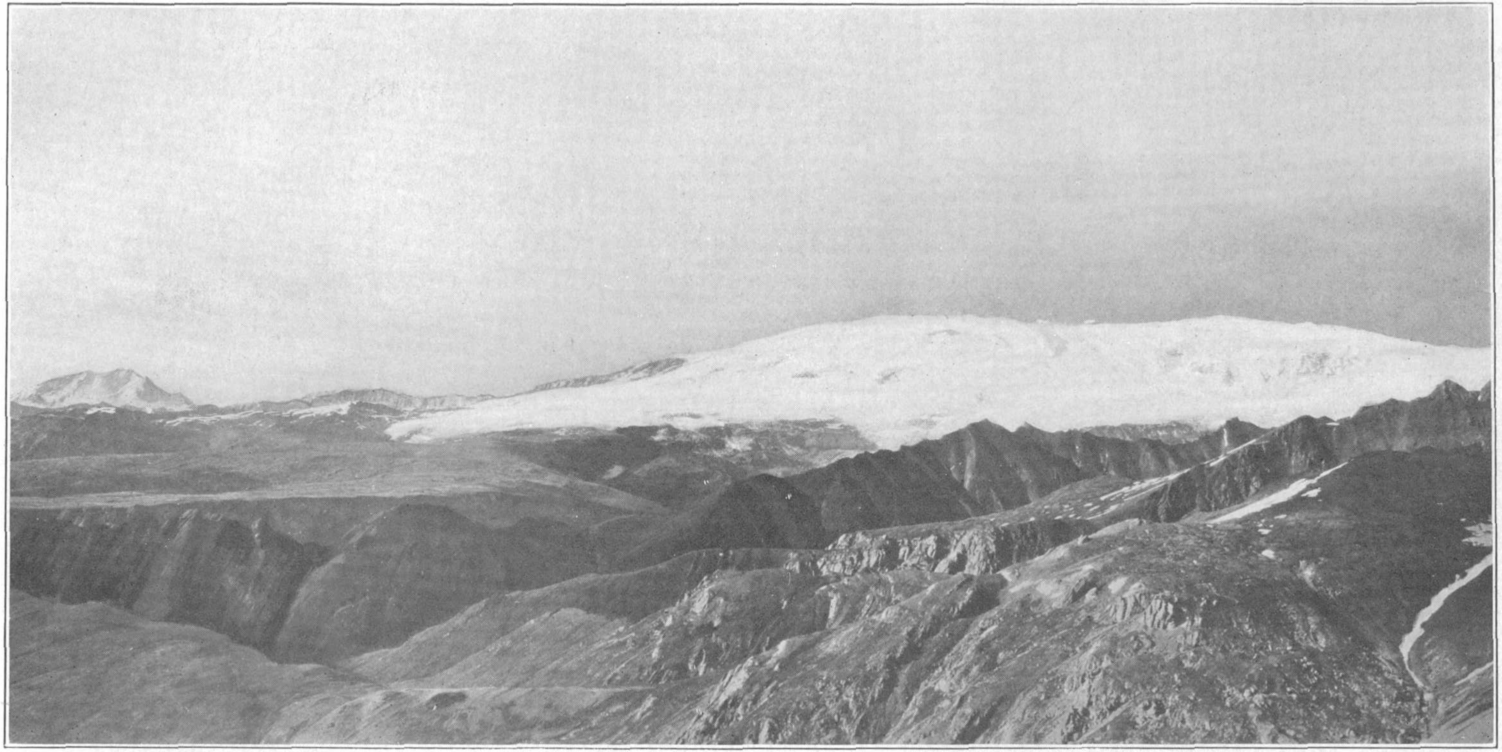
KOTSINA RIVER A FEW MILES BELOW THE MOUTH OF ELLIOTT CREEK, LOOKING SOUTHWEST.



A. PANORAMA OF MOUNT BLACKBURN AND ADJACENT MOUNTAINS, FROM A HIGH POINT NORTH OF SLATKA CREEK.

B. NORTH SLOPE OF ELLIOTT CREEK VALLEY.

Shows the scarp of the Chitistone limestone, beneath which is the Nikolai greenstone. The rugged ridge above the limestone is conglomerate.

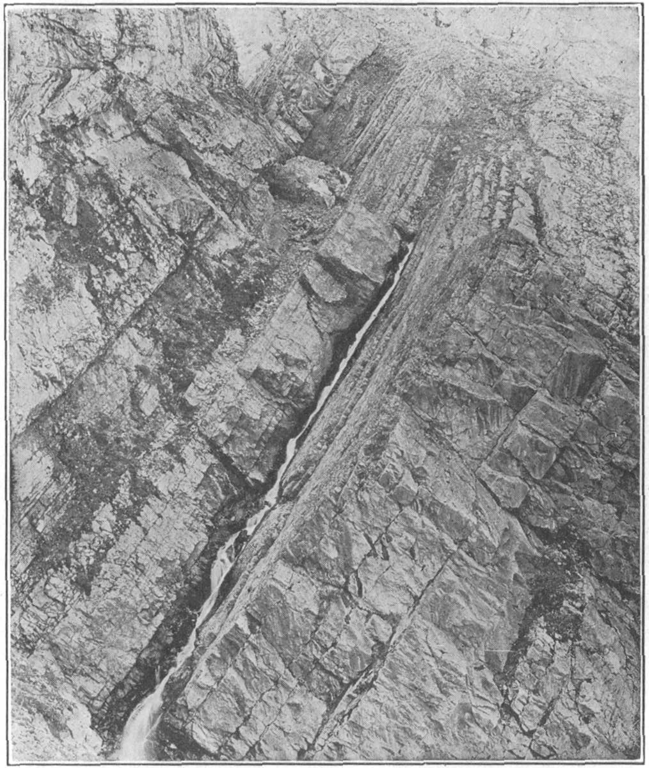


MOUNT WRANGELL FROM THE MOUNTAINS WEST OF KLUVESNA RIVER.

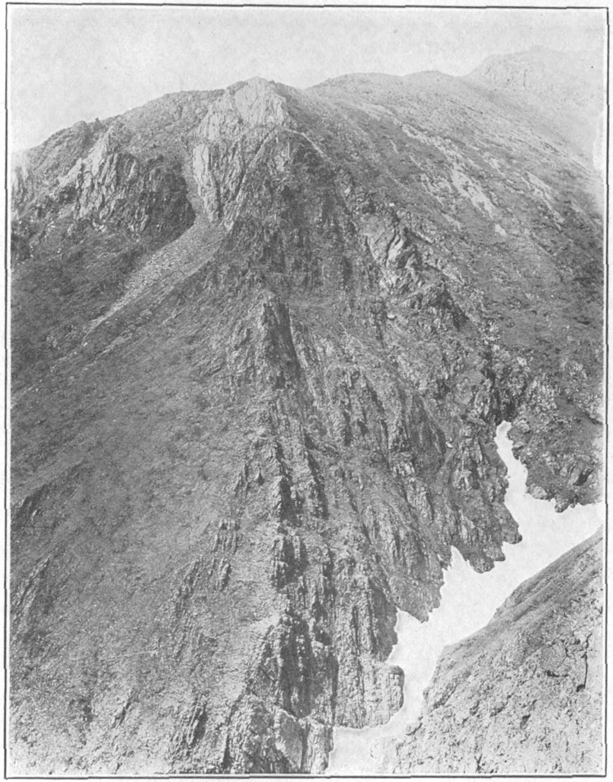
Mount Drum on the extreme left. Taken from an altitude of about 6,000 feet.

VALLEY OF LIME CREEK

Nikolai greenstone on the left; scarp of Chitistone limestone on the right.



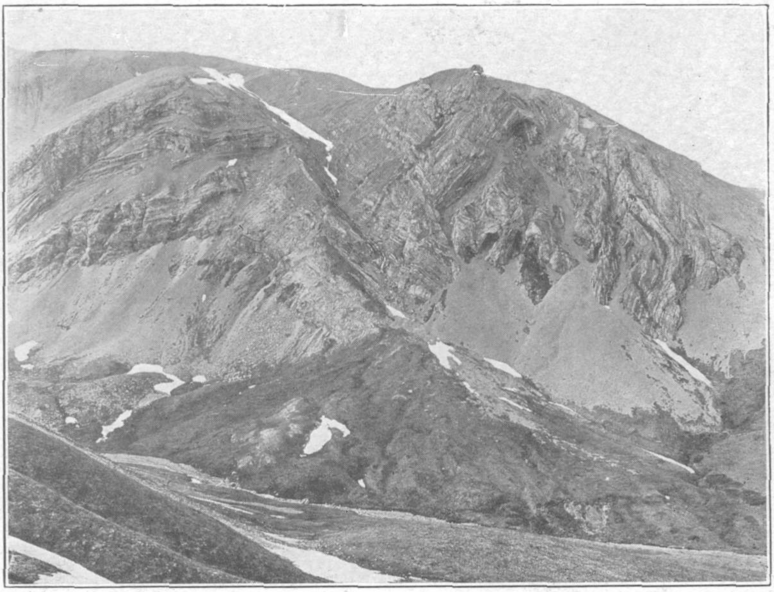
A. THIN BEDS IN THE CHITISTONE LIMESTONE WEST OF KLUVESNA RIVER.



B. FOLDED AND SHEARED CARBONIFEROUS LIMESTONE ON IRON CREEK.

A. MOUTH OF PEACOCK CREEK.

Shows a canyon cut through the lip of a hanging valley.



B. FOLDED AND FAULTED TRIASSIC LIMESTONES ON THE WEST BRANCH OF ROCK CREEK.

Talus at the left almost conceals the Nikolai greenstone.

in the Kotsina basin. Copper, Rock, Roaring, and Peacock valleys (Pl. IX, *A*) exhibit this feature well, although each stream has cut at its mouth a steep, narrow canyon to the level of the main valley. Nugget Creek and Slatka Creek, tributaries to the Kuskulana, also have fine hanging valleys. This feature is not so pronounced on the other streams flowing into the Kuskulana, for the valley of that river is broad and its walls have a gentler slope than those of the Kotsina.

The truncated spurs and straightened, oversteepened walls of Kotsina and Kuskulana valleys have been mentioned. Similar features are well displayed along the southwest border of the district, where the great Chitina Glacier impinged on the mountain wall of its valley. The straight front of the ridge and the triangular faces of the interstream mountain masses attract the attention of every observant person.

Some of the topographic forms in the district are evidently dependent on geologic structure and the difference in hardness, resistance to weathering, and other characteristics exhibited by the geologic formations. The valleys of lower Rock Creek, Lime Creek, and Clear Creek and the ridges that bound them on the west are the product of both of these causes. The scarp of the westward-dipping Chitistone limestone determines the ridges and has controlled the position of the streams that flow along them. A glance at the geologic map (Pl. III, in pocket) will make this clear. The Chitistone limestone forms many bold cliffs and prominent points throughout the district, for it breaks down in blocks, controlled by the joint planes, and does not disintegrate in place. In a similar way the Nikolai greenstone also breaks down along joint and fault planes, but owing to its greater thickness, the absence of soft beds above and below it, and other causes the topography of the greenstone areas is unlike that of the limestone areas. In particular, the long precipitous walls, like the limestone walls on Lime Creek and on Elliott Creek, are not formed on the greenstone. The greenstone weathers into rough, craggy slopes, steep and inaccessible in many places, with smooth talus slopes below. On the other hand, the shale formations yield forms with smooth contours, even where weathering is proceeding at a rapid rate, for the rock breaks down in smaller fragments, which disintegrate readily. The area south of Kotsina River, between Copper and Rock creeks, shows well the characteristic topography of shale areas.

One other peculiar topographic form is conspicuous in areas of massive conglomerate like that at the head of Strelna Creek and in the ridge north of Elliott Creek. The rough surface and black color of the mountains formed of the conglomerate often makes it possible to recognize the formation at a long distance. Huge pillars and blocklike masses are common on the crests of the conglomerate ridges and make walking there impossible.

The position of some of the valleys has most probably been influenced by faults. Examples are the part of the west fork of Rock Creek that runs northwestward and the branch of Strelna Creek in line with it, possibly also the east forks of Rock Creek and Lime Creek. Yet many of the faults have no recognized topographic expression.

CLIMATE.

The Wrangell Mountains form the eastern wall of a broad basinlike depression that is inclosed on the remaining three sides by the Alaska Range and the Talkeetna and Chugach mountains. Copper River flows along the eastern margin of this basin, and the headwaters of Matanuska, Susitna, and Delta rivers drain its western and northern margins. This basin, although very small in comparison with the rest of Alaska, forms one of the climatic provinces into which Abbe[5] divides the Territory. It has low precipitation and a wide range of temperature.

The Kotsina-Kuskulana district lies at the border of this basin, but its climate, particularly the rainfall, does not fully correspond with that of the Copper River lowland, to the northwest. The mountainous character of the district is the chief cause of such differences as exist. Nevertheless the weather records of Copper Center, 35 miles from the nearest point on Kotsina River, are useful in helping form an idea of the climate of the district, and a summary of them, prepared by Ellsworth and Davenport,[6] is given here.

Summary of precipitation and temperature at Copper Center for a period of 7 full years and 22 scattering months (August, 1902–November, 1913).

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Year.
Mean precipitation, inches	0.57	0.46	0.17	0.07	0.39	0.86	1.56	1.12	1.13	0.96	0.76	0.74	8.79
Temperature (°F.):													
Maximum	49	49	49	64	80	96	87	87	80	66	49	50	......
Minimum	−74	−55	−48	−26	18	22	22	20	3	−26	−46	−53	......
Mean	−10.8	2.3	14.3	29.0	44.1	53.1	55.4	52.4	42.9	27.7	4.6	3.3	27.1

These records were made at a station in the open Copper River basin, 15 miles from the Wrangell Mountains, so that in order to have figures for comparison which are more nearly like those that might be expected from the Kotsina and Kuskulana valleys, a table based on observations made at Kennecott, in the Nizina district, is

[5] Abbe, Cleveland, jr., U. S. Geol. Survey Prof. Paper 45, p. 140, 1906.

[6] Ellsworth, C. E., and Davenport, R. W., Preliminary report on a water-power reconnaissance in south-central Alaska: U. S. Geol. Survey Bull. 592, p. 159, 1914.

also given. The record covers a period of years from 1905 to 1920 but is imperfect and is therefore given without an attempt at summarization.

Record of temperature and precipitation at Kennecott, in the Nizina district of Chitina Valley.

[T=Trace.]

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Temperature (°F.):												
Maximum—												
1905	......	......	......	......	......	......	......	......	......	58	53	36
1906	37	39	......	......	......	74	......	......	59	56	43	......
1909	......	......	......	......	......	79	73	69	64	54	30	40
1910	33	34	45	45	65	70	73	72	60	......	......	......
1911	......	......	......	......	......	......	......	......	66	48	42	37
1916	......	......	......	......	......	......	......	72	......	56	44	39
1917	41	46	45	58	67	72	74	72	74	52	42	......
1918	35	41	43	42	61	72	78	70	66	58	39	39
1919	40	34	38	51	59	......	76	68	68	......	......	......
1920	38	40	38	47	65	76	72	......	57	42	38	......
Minimum—												
1906	......	......	......	......	......	......	......	......	23	14	−10	......
1909	......	......	......	......	......	29	34	32	11	3	−27	−25
1910	−26	−31	−29	−1	20	27	35	31	24	......	......	......
1911	......	......	......	......	......	......	......	......	28	14	−14	−27
1916	......	......	......	......	......	......	......	36	......	4	−16	−30
1918	−16	−20	−19	−3	22	32	38	34	30	−4	−13	−36
1919	−29	−22	−17	12	21	......	37	30	26	......	......	......
1920	−35	−10	−18	−15	19	33	39	......	25	−2	−15	......
Mean—												
1906	......	......	......	......	......	......	......	......	42	34	16	......
1909	......	......	......	......	......	47	51	49	38	24	−1	10
1910	4	1	16	24	41	47	50	47	43	......	......	......
1911	......	......	......	......	......	......	......	......	44	34	12	10
1912	6	19	24	31	44	46	52	48	44	31	18	......
1916	......	......	......	......	......	......	......	51	......	35	16	2
1918	5	6	9	28	40	51	57	51	48	31	19	10
1919	7	9	15	35	42	......	52	51	45	......	......	......
1920	−4	26	14	26	42	52	53	......	40	26	10	......
Precipitation (inches):												
1918	......	......	.69	......	.25	4.25	.31	1.99	2.31	1.10	2.18	1.69
1919	1.03	.15	.18	T.	1.44	T.	2.20	......	2.00	1.07	1.04	1.55
1920	.29	......	2.26	......	......	1.80	T.	3.40	......	......	.91	......

No printed weather records taken within the district were available when the geologic mapping was completed, but a Weather Bureau station has since been established at Strelna, where observations are now made by Mr. V. J. Dwyer. If records were at hand for comparison it would doubtless be found that the precipitation on the mountainous parts of the Kotsina and Kuskulana drainage basins is considerably greater than at Copper Center and that the range of temperature is somewhat less. In the paper by Ellsworth and Davenport previously cited the Copper Center records are compared with those of stations on Prince William Sound and near-by coastal points as follows:

The records show that the heaviest precipitation along the coast occurs during September, November, and December; farther inland the months of maximum precipitation are July, August, and September. The mean monthly temperature is below freezing for seven months in the year at Copper Center and for four to six months on the coast. The average number of rainy days in a year is 63 at Copper Center, about 150 at Seward and Sunrise, from 150 to 200 at Valdez, and about 200 at Cordova and Katalla.

Records of snowfall are rather meager but indicate about 10 feet annually at Cordova, 12 feet at Valdez, 6 feet at Seward, and 3 feet at Copper Center. In the mountains the snowfall is much greater and accumulates in enormous drifts, which in sheltered spots last throughout the summer.

The summers of the Chitina and Copper river valleys are short and pleasant, the temperatures are generally moderate, although high at times, and there are many clear days, particularly in the spring and early in summer. The ice goes out of the Chitina late in April or early in May. Snow disappears from the lower valleys by the middle of May, but in the upper valleys, in gulches and protected places, it persists till late in the summer or does not melt at all, although most of the Kotsina-Kuskulana district is below the line of perpetual snow. Around the head and on the south wall of the Elliott Creek valley slides fill the gulches and cover the slopes with snow that lasts till the end of July (Pl. X, *A*, p. 30).

Frosts may occur in the valleys in any month of the year but are uncommon in June and July. A slight fall of snow may be seen on the high mountain tops after almost every summer rain, lasting a day or more, but the snow disappears in a few hours when the clouds lift. The lower limit of the heavy storm clouds marks the lower limit of summer snow. Below this plane precipitation takes the form of rain. Many of the rains are entirely local, being confined to one of the larger valleys or to one side of a ridge. At times rain falls only in the mountainous area, while the clouds are absent and the sun is shining over the lowland area.

In summer, during the warm days of late June and of July, the large trunk streams that head in glaciers, such as Kluvesna, Kotsina, and Kuskulana rivers, have their maximum discharge. This statement, however, refers to normal conditions and excludes such unusual flows as those that take place on the bursting of the glacial lake at the head of Kotsina River and the disastrous floods of September, 1912. High water on the smaller streams comes in June, when the snows are melting in the mountains, and subsides, except at times of heavy rain, when the snow is gone. The period of high water in the large streams is therefore longer than on most of the tributaries, for the glaciers are a source of supply that never fail till cool weather puts an end to the melting of the ice.

Some measurements of stream flow made by Ellsworth and Davenport[7] are of interest, although such detached observations can have no value as a basis for engineering calculations.

[7] Op. cit., p. 167.

Miscellaneous measurements in Copper River drainage basin in 1913.

Date	Stream.	Tributary to—	Locality.	Discharge.	Drainage area.	Discharge per square mile.
				Sec.-ft.	*Sq. miles.*	*Sec.-ft.*
Nov. 9	Kotsina River	Copper River	Near mouth	200	447	0.45
Nov. —	Nizina River	Chitina River	Above Kennicott River.	492	865	.57
May 31	Dan Creek	Nizina River	Above hydraulic plant.	37	40	.92
June 1	White Creek	Chititu Creek	Above Jolly Gulch	14.1	9.4	1.50
3	Chititu Creek	Nizina River	Below Rex Creek	53	24	2.21
3	Rex Creek	Chititu Creek	Above hydraulic plant.	18.4	9.5	1.94
Nov. 5	McCarthy Creek	Kennicott River	Above Nikolai Creek	21	48	.44
June 9	Lakina River	Chitina River	Railroad crossing	[a] 1,750	124	14.11
Oct. 3	do	do	do	224	124	1.81
31	do	do	do	99	124	.80
June 10	Gilahina River	do	do	212	56	3.79
Oct. 2	do	do	do	81	56	1.45
June 10	Chokosna River	Gilahina River	do	241	43	5.62
11	do	do	do	172	43	4.00
Oct. 1	do	do	do	69	43	1.60
May 23	Kuskulana River	Chitina River	do	145	221	.66
June 11	do	do	do	603	221	2.73
Oct. 1	do	do	do	[b] 500	221	2.26
Nov. 7	do	do	do	130	221	.59
June 11	Strelna Creek	Kuskulana River	do	46	25	1.84
27	do	do	do	55	25	2.20
Sept. 30	do	do	do	24	25	.96
Nov. 6	do	do	do	3.3	25	.13
Oct. 20	Tsina River	Tiekel River	Below Ptarmigan Creek.	87		
Nov. 9	do	do	do	50		
10	do	do	Mouth	134	161	.83
June 13	Tiekel River	Copper River	do	5,820	408	14.3
July 1	do	do	do	8,480	408	20.8
Sept. 10	do	do	do	819	408	2.01
Oct. 17	Ptarmigan Creek	Tsina River	Below lake at head of upper canyon.	11.9	7.7	1.55
Nov. 8	do	do	do	2.8	7.7	.36
Oct. 18	do	do	2 miles above mouth at head of lower canyon.	22	16	1.38
Nov. 11	do	do	do	23	16	1.44
Oct. 19	Stuart Creek	do	Mouth	14.8		
Nov. 10	do	do	do	8		
Oct. 19	Kanata River	Tiekel River	do	146	175	.83
Nov. 10	do	do	do	69	175	.39
July 26	Salmon Creek	Alaganik Slough	Below forks	119		

[a] Float measurement. [b] Estimated.

The early winter snows begin in September. The first falls rarely last more than a few days, but gradually the snow line creeps down the mountain slopes, reversing the direction of its spring movement, till finally it reaches the lower valleys in October or early in November. Although snow comes early in this district, the heavy falls do not take place till the middle or later part of winter.

Winter work in many places in the mountainous parts of this region is made dangerous by snowslides. All the valleys of the Kotsina-Kuskulana district are subject to them. Nine men have been killed in this way during the last few years, and others either have been seriously injured or have narrowly escaped with their lives.

An unusual quantity of snow fell in the winter of 1913–14. It reached a depth of 5 or 6 feet at Strelna and lay on the ground for two weeks later than is common, so that the grass and leaves were backward in coming out. The month of June was clear, warm, and almost without rain. Most of July also was pleasant, with occasional rains, but August and the first half of September were foggy or stormy, with only a few clear days. Cold, clear weather, with temperatures as low as 12° F., followed the stormy period and lasted for a week or ten days till the early winter snows began.

VEGETATION.

The vegetation of a region interests most prospectors and miners only so far as it directly affects their work. Miners and those who investigate mining properties wish to know the quantity and distribution of timber available for lumber and general use and of grass suitable for forage or the extent to which moss and bushes cover the hard-rock formations and thereby increase the difficulty of discovering ore bodies. Only such general subjects as these can be considered here.

Vegetation covers the lower lands and the mountain slopes of the district to an altitude of 4,000 or 5,000 feet and shows a scanty growth at still higher levels. It grows luxuriantly in the valleys where conditions are favorable but becomes more and more dwarfed as the altitude increases. Timber line ranges from 2,500 to 3,000 feet above the sea, yet in several localities a few small, gnarly spruces were seen at 4,000 feet. Above timber line and extending somewhat below it is a belt in which alder, associated in places with willows, small cottonwoods, and aspens, prevails. The alder, however, is not so large or so abundant as on the mountain sides of the coastal region. Above the alder belt is another belt made up chiefly of dwarf birch or "buck brush," with a few small willows. Above this come mosses, a sparse growth of grasses, and numerous small plants, forming the higher zone of vegetation.

Spruce and cottonwood are the large trees of the region and are the trees usually referred to as timber. Spruce is widely distributed at all elevations below timber line. (See Pls. IV and XIII, *B*, pp. 6, 31.) Large cottonwoods, on the other hand, are restricted to the gravelly benches and bars of the lower valleys. They are of little if any value for lumber but are useful for house logs if suitable spruce is not at hand.

Much of the spruce is of fair size and good quality. Trees from 18 inches to 2 feet in diameter at the butt are found in the better stands of timber. Such trees, however, form only a very small proportion of the whole growth and are short in comparison with trees of the same diameter on the Pacific coast of the United States. Few if any of them would furnish a timber 10 inches square and 30 feet long.

The best timber (fig. 1) is found on the bench land along the southwest side of the district, on the benches in the lower part of Kuskulana Valley, and in the lower part of Kotsina Valley. Very good timber is found also on the lower part of Elliott Creek. Away from the mountains in the open Chitina Valley the trees are small and scrubby except a border of a larger growth along the stream bottoms. They are scattered over a moss-covered morainal lowland that becomes in part an almost impassable swamp during the rainy

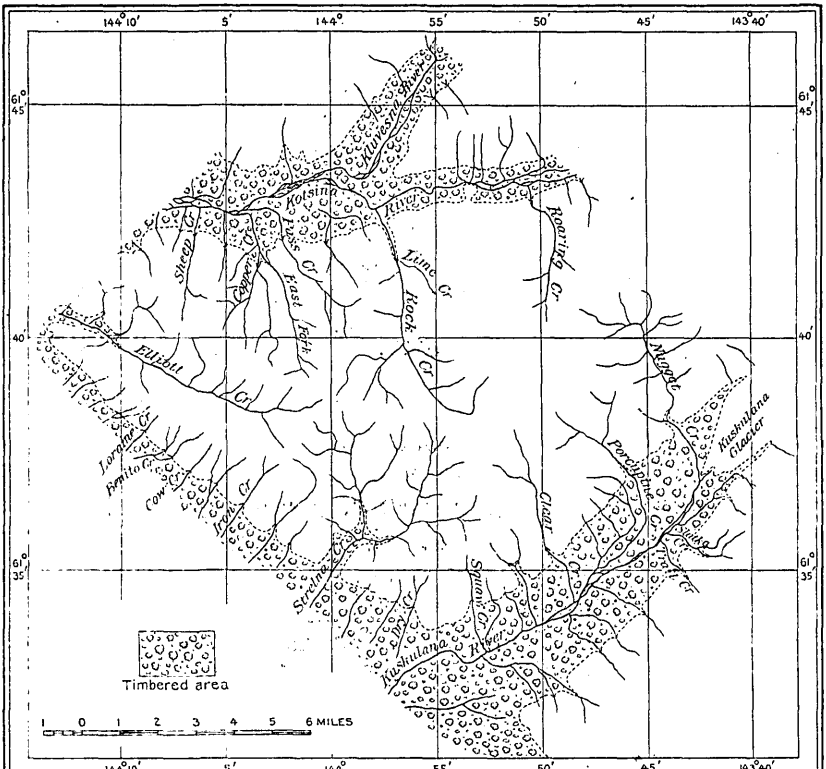


FIGURE 1.—Map showing the distribution of timber in the Kotsina-Kuskulana district.

seasons. Most of this timber has no value except for firewood. In many localities the timber on the better-drained ridges has been burned and is replaced by a dense growth of small willows.

In a few places, such as Nugget Creek, parts of the Kuskulana Valley, the mouth of Surprise Creek, and an area near Fall Creek on Kluvesna River, the trees and small brush were burned purposely to give the grass a chance to grow. In this way excellent pasturage for stock has been provided.

Grass is not abundant in most of the Kotsina-Kuskulana district. Near timber line it grows best and is sufficient for any demands likely to be made on it for local grazing needs but shows no such luxuriant growth as the grass of Kenai Peninsula and the Cook Inlet and Susitna River regions. No grass grows in the timbered areas except where the timber has been burned, and even there it requires years to become established, particularly on the level gravel benches like those forming the floor of Kuskulana Valley above Clear Creek. The hill slopes are more favorable to its growth. When the brush has been killed by fire grass comes up quickly and soon becomes well established. All the best pasturage of the district has been obtained in this way.

Currants and blueberries are plentiful in certain localities. Currants are perhaps more common than the blueberries. They are found frequently underneath the scattered alders and in the open spaces between them and form a welcome addition to the table fare in August and the early part of September.

Those who have never visited Alaska and hold the common ideas of its climate and vegetation would be surprised to see the variety and abundance of its wild flowers. They are no less attractive in the Kotsina-Kuskulana district than in most of the remainder of the Territory.

GAME.

Several of the larger Alaskan game animals are found in the Kotsina-Kuskulana district. Among them sheep, bear, and lynx are the most common. Moose have been seen but so rarely that they hardly deserve to be included in the list.

Both sheep and bear are less plentiful than when white men first entered the district. It is evident to anyone who travels the higher ridges and sees the well-marked trails that sheep must at some time have been more numerous than now. This is confirmed by the testimony of prospectors who have been in the country since the early days. A great many sheep have been killed for meat during the last 17 years, but the number killed at present is less than a few years ago, when the white population of the district was greater. Sheep are not found on some of the feeding grounds that they formerly frequented, and the prospector in search of meat is generally obliged to go farther and work harder for his supply. About 50 sheep were seen by members of the United States Geological Survey party in 1914.

Most of the bears of the district are of the black variety. They prefer the wooded areas and the brushy mountain slopes, where they can keep under cover and avoid being seen. A large brown bear, probably a variety of grizzly, lives in the vicinity of the glaciers and is sometimes seen on the glaciers or on the bare mountain sides near the glaciers. It is much less common than the black bear.

A good many lynx are caught by trappers, but ordinarily the lynx keeps himself well hidden so that it is rarely possible to catch sight of him. As one of his principal food sources is rabbit, the number of lynx bears a direct relation to the number of rabbits. When rabbits are plentiful the number of lynx increases; when the rabbits die off, as they do periodically, the lynx decreases in numbers.

Rabbits were exceedingly plentiful during the three years 1912–1914 and were present everywhere in the brush-covered areas. Many acres of small willow and dwarf birch or buck brush were eaten by them during the two winters. When food is scarce they cut off the twigs and smaller branches at the snow level or peel the bark from larger ones, leaving a stubble of bare white sticks that looks like a field after the grain has been cut.

The wolverine is not common but occasionally is known to rob a poorly protected cache or the traps of hunters. Several small fur-bearing animals are found in the district and are taken by the trappers. Martin, mink, and weasel or "ermine" are the principal ones.

The game birds are ptarmigan and spruce grouse. Two species of ptarmigan are present. The larger one frequents the willow thickets near timber line, especially at the upper ends of the valleys. A smaller variety lives at higher elevations on the rocky mountain slopes. Like the rabbits and the spruce grouse, the ptarmigan have favorable seasons when their numbers increase and unfavorable seasons when they diminish. The season of 1914 was unfavorable, and ptarmigan were scarce in comparison with their numbers in the two preceding seasons. Possibly this was due to the slowness with which the winter snow melted, causing a late spring and cool weather during nesting time. Possibly also the numerous lynxes may have killed many of the old birds and the young ones.

The spruce hen lives in the timbered areas but seems to avoid wet, marshy places. On sunny mornings late in summer and early in fall it is often seen on the dry gravel and sand patches near streams and trails or on the railroad tracks. It either has little fear of man or else no realization of danger and is easily shot. The spruce hen, like the rabbit, is periodically abundant and scarce.

Trout live in some of the streams of the district. Although they usually avoid the milky water of glacial streams, at times they are numerous in such streams at the mouths of clear-water tributaries. They are present also in the swift water of the large clear-water creeks and in the deep quiet water where some of these creeks flow across the valley floors.

TRAILS AND TRANSPORTATION.

Since the Copper River & Northwestern Railway was completed the problem of reaching the Kotsina-Kuskulana district and of transporting supplies to it has been much simplified. The nearest station on the railroad is Strelna, on Strelna Creek, 4 or 5 miles from the boundary of this district. Strelna is 146 miles from Cordova. The next near point is Chitina, 131 miles from Cordova. Chitina is about 1 mile from the point where Kotsina River joins Copper River and is about 12 miles from the nearest point in the Kotsina-Kuskulana district.

All summer travel to Kuskulana River and Elliott Creek and most of that to Kotsina River now goes through Strelna. A wagon road leads from Strelna up Kuskulana River to Nugget Creek. From this road a horse trail branches off to Elliott Creek and another into the upper Strelna Valley, whence other trails lead to Rock Creek, Pass Creek, and Elliott Creek.

The Kuskulana road follows Strelna Creek northward for about 2 miles, then turns eastward and crosses 3 or 4 miles of flat swampy country, covered with the scrubby spruce, to the Kuskulana Valley. This road is suitable for automobile trucks and was used a great deal in 1918 and 1919. The distance from Strelna to Clear Creek by the road is between 11 and 12 miles. A good trail leads up Clear Creek. Another ascends Nugget Creek above the camp on that stream, from which it is possible to cross over the high divide to Roaring Creek. The old trail to the Nizina follows Trail Creek to Kuskulana Pass. Other trails lead up Porcupine Creek, up both sides of Kuskulana Glacier, up Slatka Creek, and to the different mining properties.

All the trails in the Strelna Creek valley afford firm footing for horses but have a few steep places. The three passes leading to Rock, Pass, and Elliott creeks have altitudes of 5,100 to 5,200 feet. They are difficult early in summer, on account of the snow on the steep slopes below them.

The trail to Elliott Creek leaves Strelna Creek 2½ miles from Strelna and takes a northwesterly course to Cow Creek, whence, continuing northwestward, it gradually climbs the southwest slope of the mountain south of Elliott Creek and crosses the northwest end of the ridge at an elevation of 3,500 feet. Thence it turns directly east and reaches Elliott Creek by a steep descent which ends just above the mouth of Five Sheep Creek. The distance by direct line is about 14 miles, but the distance covered by the traveler is considerably greater owing to crooks in the trail. Parts of the trail are hard to travel in wet weather, although they offer little difficulty during much of the summer. This trail is used regularly by pack horses carrying supplies to Elliott Creek but is not suitable for trucks or automobiles.

A good trail follows the north side of Kotsina River from Kluvesna River to the Copper River valley. It was laid out by A. K. Crawford and Adolph Ammann, who also built the bridge over Kluvesna River. Since Mr. Crawford's death Mr. Ammann has kept both the bridge and trail in repair. Branch trails lead up Kluvesna River and the Kotsina, and from them other trails have been built up all the streams where copper prospects are situated. There are trails on Fall, Copper, Rock, Roaring, Peacock, and Surprise creeks. A wagon road leads from the camp of the Great Northern Development Co. on Kotsina River to the upper camp on Amy Gulch.

The trails that have been mentioned were nearly all intended for pack trails and are unsuited for wagons. Some of them, however, could be made into roads without great difficulty.

Until the Copper River & Northwestern Railway was put through the supplies used by prospectors in this district were brought to the camps in winter. Part of the supplies used on Kotsina River in 1914 were freighted from Valdez, but doubtless in future supplies will be brought from Chitina rather than Valdez. Freighting from Chitina to the Kotsina Valley in winter is less expensive than freighting from Strelna, for, although the distance is a little greater, the ice of Kotsina River furnishes a better sled road. The same is true of winter freighting to Elliott Creek. Supplies may now be obtained in Kuskulana Valley at any season, for all the main distributing camps may be reached either by wagon or by automobile.

If copper mining becomes established in this district, spurs from the railroad will doubtless be built to several of the creeks. Two such spur roads have already been surveyed. One leads to Elliott Creek from a point on the railroad between Strelna and Copper River. The other branches from the railroad at Strelna and runs up Kuskulana Valley. The latter offers no unusual engineering difficulties and can be built with comparatively small cost. The branch to Elliott Creek has less favorable grades and would require more rock work, so that the average cost per mile would be greater. As an alternative means of transporting ore to the present line of railroad, the Hubbard-Elliott Co. has proposed constructing a tramway over the mountain from Elliott Creek to Strelna. A railroad into Kotsina Valley would probably require one or more expensive bridges. Aside from this the engineering difficulties would be of about the same order as those on a road into Elliott Creek. A wagon road into Kotsina Valley from some point on the railroad would be of great benefit to the prospectors now at work there.

POPULATION.

The population of the Kotsina-Kuskulana district in the summer of 1914 was about 60, all but two of whom were men. Not more than half a dozen of these men remain in the district during the winter;

part of them go to points in the States; the rest to Chitina, Cordova, Valdez, or other Alaskan towns. The population is largely a summer population that varies with the amount of assessment work or development work to be done. In 1919 the population was considerably less than in 1914, for the war took some who had not returned, and the law exempting owners from the necessity of doing assessment work left some streams, such as Kotsina River and Elliott Creek, without inhabitants.

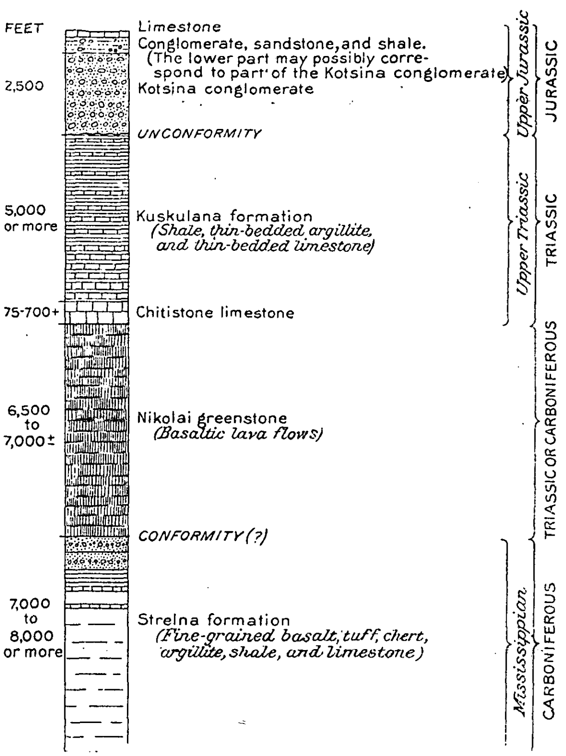


FIGURE 2.—Columnar section showing the formations represented on the geologic map of the Kotsina-Kuskulana district.

None of the native population live permanently within the area mapped, although most of the Indians who formerly lived at Taral, on the east side of Copper River below the mouth of the Chitina, have built cabins at Strelna and live there the year round. Nearly all the Indian men are at work in some capacity much of the time. They are employed as section hands on the railroad, as waiters or guides, or in almost any labor requiring unskilled workmen.

DESCRIPTIVE GEOLOGY.

By F. H. MOFFIT and J. B. MERTIE, Jr.

STRATIGRAPHY.

OUTLINE.

The geologic map (Pl. III, in pocket) shows the areal distribution of the formations within the Kotsina-Kuskulana district. Figure 2 shows diagrammatically the stratigraphic relations of the rocks represented on the map.

Six hard-rock formations are recognized. They are, in order of age, from oldest to youngest, the Strelna formation, the Nikolai greenstone, the Chitistone limestone, the Kuskulana formation, the Kotsina conglomerate, and the later Jurassic limestone, shale, sandstone, and conglomerate succession. In addition there are surface deposits consisting principally of stream gravels, glacial débris, and unsorted rock waste.

As may be seen from figure 2, the oldest rocks recognized within the district belong to the Strelna formation. This formation includes both igneous and sedimentary rocks. It consists chiefly of stratified tuff beds and dense fine-grained basalts. With the tuffs and basalts are associated a minor amount of argillaceous and sandy shale, thin-bedded cherts, and, locally, beds of limestone in varying stages of silicification. In a number of places the rocks of the Strelna formation are cut by intrusive masses of diorite and gabbro, more or less altered. The thickness of the Strelna formation is probably between 7,000 and 8,000 feet but may reach 10,000 feet.

The Nikolai greenstone is made up of flows of amygdaloidal basalt (Pl. XVI, *A*, p. 38) resting without apparent unconformity on the underlying tuffs and fine-grained basalts of the Strelna formation. These flows have undergone extensive chemical alteration, as have also the underlying rocks, and are the typical Nikolai greenstone of the Nizina district. The thickness of the basalt flows within the Kotsina-Kuskulana district is thought to range from 6,500 to 7,000 feet. The total thickness of the Nikolai greenstone and Strelna formation thus appears to be from 13,500 to 14,500 feet, yet it is recognized that there may be a considerable error in these figures. A few fossils were collected from limestone and argillaceous beds in the Strelna formation, and they furnish the evidence on which the limestone and associated sedimentary and igneous rocks are assigned to the lower Carboniferous (Mississippian) epoch.

The Chitistone formation is a bluish-gray limestone whose thickness in this district ranges from 75 to 700 or possibly 1,000 feet. In the lower part it is massive and without distinct marks of stratification, but in the upper part it is thin bedded, and the bedding planes are conspicuous. It grades without marked stratigraphic break into the thin-bedded limestones of the overlying Kuskulana formation. Although it is of Upper Triassic age it appears to lie without depositional unconformity on the Nikolai lavas (Permian or Triassic).

The Kuskulana formation comprises a great thickness, possibly 5,000 feet or more, of shale, thin-bedded argillite, and thin-bedded limestone. Shale forms the upper part of the formation. Between the massive Chitistone limestone and the shales in the upper part of the Kuskulana formation there is a transition zone of greatly varying thickness, made up of thin-bedded limestone, shale, and argillite. In some places this zone is almost lacking; in others it reaches a thickness of many hundred feet. The Kuskulana formation has been deformed along with the older rocks, but on account of its relative weakness it shows much more pronounced folding. It is of Upper Triassic age.

Unconformably overlying the Kuskulana and older formations is the Kotsina conglomerate, probably of Upper Jurassic age. It consists of waterworn pebbles and cobbles inclosed in a shaly or arkosic matrix. The component pebbles are plainly derived from the formations already mentioned and from the intrusive rocks in them. The conglomerate weathers readily, yielding a characteristic rugged topography. Measurements of its thickness are of doubtful accuracy, but in the mountains north of Elliott Creek the conglomerate probably is from 1,500 to 2,000 feet thick.

The Jurassic rocks of this district in addition to the Kotsina conglomerate comprise limestone, sandstone, sandy limestone and shale, and fine conglomerate or grit. These beds are not widely distributed in the district and have heretofore been considered part of the Kennicott formation (Upper Jurassic). At one place the higher beds appear to rest unconformably on fine sandstone or grit that is referred to the Jurassic. The beds are highly fossiliferous. They have a thickness of possibly 500 feet east of Kuskulana River and of 880 feet west of the river, but in general the thickness is much less, not exceeding 100 or 200 feet.

All the formations previously mentioned, with the possible exception of the Jurassic limestone and sandstone beds, are intruded by igneous rocks. These intrusives are most common in the older formations, particularly in the Strelna, in which the largest intrusive masses are found. They include pyroxene diorite, gabbro, granodiorite, quartz diorite, quartz diorite porphyry, and quartz latite. Dikes and sills are numerous in certain areas of the Kuskulana formation but are not common in the Chitistone limestone or the Kotsina conglomerate. The intrusive rocks probably belong to several periods and range in age from lower Carboniferous to post-Cretaceous.

All the sedimentary formations and associated lava flows have been folded and extensively faulted. The folding is greatest in the formations below the Kotsina conglomerate, yet in places the Jurassic limestone and sandstone beds show pronounced folding. These beds, like the Kuskulana shale and limestone, were less able to resist pressure than the more massive lava flows, limestone, and conglomerate. Thrust faulting is the common type of displacement, but folding has combined with faulting in some places to produce complicated and anomalous results.

In addition to folding and faulting the Strelna formation and Nikolai greenstone have undergone metamorphic changes not seen in the overlying beds. Chemical alteration has taken place, especially in all the lava flows of the Nikolai greenstone, and locally, along zones of intense pressure, a schistose structure has been produced, particularly in the Strelna formation.

Unconsolidated surficial deposits are widely distributed in the area. They include present stream gravel, the bench gravel deposited by streams in an earlier period of their history, morainal deposits, and accumulations of unsorted débris such as talus and other rock waste not subject to the action of running water in streams.

In the pages that follow these formations will be described in greater detail, their stratigraphic and structural relations will be explained, and their history will be interpreted so far as possible from the evidence at hand.

PALEOZOIC SEDIMENTARY ROCKS.

SEDIMENTARY BEDS OF THE STRELNA FORMATION (MISSISSIPPIAN).

CHARACTER AND DISTRIBUTION.

The basal formation of the geologic column in the Kotsina-Kuskulana district is a complex composed of bedded lavas and tuffs intercalated with sedimentary beds and cut by basic intrusive rocks. To this complex of igneous and sedimentary rocks the name Strelna formation is here given, from their occurrence in the valley of Strelna Creek. The volcanic rocks of this formation will be described separately by Mr. Mertie in the section that deals with igneous rocks (p. 55), but the sedimentary members and the evidence for the age of the whole formation are considered here.

Schrader and Spencer,[8] in 1900, noted the presence of " sediments, including limestones, shales, and coarse conglomerates, with intercalated sheets or flows of basalt like the Nikolai greenstone," on Kotsina River in the vicinity of Long Glacier and Clear Creek and southward to Elliott Creek. Not being certain about the age of these rocks, they showed them on their reconnaissance map as rocks of unknown age. It is now evident that the rocks thus shown do not constitute a geologic unit, for some of the basal rocks were included with sediments that have since been found to be of Mesozoic age, and other portions were mapped as a part of the Nikolai greenstone. Recent work has served to separate the truly basal rocks of this district and in a certain degree to establish their relations to the overlying rocks.

The basis upon which the Strelna formation has been separated from the overlying Nikolai greenstone is strictly lithologic. In the upper valley of Kotsina River, where the geologic structure is less complex than at any other locality in the district, the relation

[8] Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, Alaska, p. 40, U. S. Geol. Survey Special Pub., 1901.

between the two formations is fairly clear. It was found that at the base of the Nikolai greenstone the lavas became less vesicular and finer grained, and that still lower in the geologic column interbedded clastic rocks began to appear. In accord with the usage of Rohn in the Nizina district, the term Nikolai greenstone is here restricted to the massive lava flows, and the line between the Nikolai greenstone and the underlying Strelna formation is drawn at that point where, in descending the geologic column, rocks thought to be of clastic origin were first encountered. Inasmuch as many of the tuffaceous members of the basal formation, especially in its upper part, are so fine grained that the clastic character is recognizable with certainty only under the microscope, and as the lavas in the lower portion of the Nikolai greenstone are dense and fine grained, the line of contact between the two formations is necessarily somewhat indefinite in places. In spite of this indefiniteness, however, the separation is entirely justified by the increasing divergence in the lithologic character of the two formations away from the contact.

Inasmuch as the sedimentary rocks and the volcanic rocks with which they are interbedded have been much folded and faulted and have undergone extensive further alteration, it was not found possible to get a clear idea of their extent and stratigraphic relations. The sediments are black argillites that locally may be described as slates, thin-bedded cherts that in part, at least, are possibly altered limestone, and more or less completely silicified limestone. They are intercalated in the tuffs, some of which appear conglomeratic, and fine-grained basalts but form only a small proportion of the total thickness of the Strelna formation. In the field it was difficult in places to distinguish between the argillites and crushed and altered phases of the dense black basalt. The cherts also present difficulties in that some of them appear to be altered thin-bedded limestone and others are more probably silicified fine-grained tuffs. Cherts are well developed in parts of the Strelna formation, but most of them are probably of the fine-grained tuff variety.

No definite sequence of the sedimentary members of the basal formation upon which further subdivision could be based was observed. In the geologic mapping it was found practicable, however, to separate most of the limestones from the rest of the formation; and these are shown on the geologic map as a separate unit. On the other hand, the gabbros and basic diorites which intrude the Strelna formation were not separated, and in the geologic mapping they are included in the block covering that formation. This was made necessary by the intimate nature of the intrusions and the alteration of the invaded and invading rocks to greenstones that resembled one another to such an extent as to make their separation at many places in the field impossible.

The limestone of the Strelna formation is white or light gray and makes rather prominent exposures. It crops out in small isolated areas, which represent parts of beds that have been much folded and faulted. Few of the limestone areas are continuous for as much as a mile, although some exposures show beds of massive limestone not less than 200 feet thick that must at one time have been part of a continuous bed of considerable extent. Plate VIII, *B* (p. 6), illustrates one of the mapped exposures of limestone on Iron Creek. The beds in this place are vertical, but the strike and dip are constant for only a short distance. In places the limestone has been so much silicified that some of the thinner beds appear to be entirely replaced by silica. A good example of this change was found on the ridge west of Iron Creek, where tuffaceous beds are overlain by limestone having a thickness between 100 and 200 feet. The base of the limestone is massive and contains fossils, but the top consists of thin cherty beds. Above the limestone is altered diorite which is overlain in turn by light-gray cherty beds that weather brownish and look like quartzite.

Argillaceous beds are found at several horizons in the basal formation. As a rule they are dark-gray well-indurated rocks without good cleavage and are best described as argillites. In a few places, as on the south wall of Elliott Creek, they have developed a good secondary cleavage and may be considered slates.

Tuffaceous beds and lava sheets constitute the major part of the Strelna formation, but the limestones and argillaceous and siliceous beds that have been described are interbedded with them, and intrusive gabbro and pyroxene diorite are found at many localities. On account of faulting and structural irregularities no complete section of the formation can be given. In general it appears to consist of two parts, of which the lower is prevailingly igneous and the upper contains the sedimentary members. The following incomplete section, from data obtained in the upper part of Nugget Creek valley, shows the lithologic variation observed at that locality. The exact position of this section in the Strelna formation is not known definitely, but it is believed certainly to be in the upper half.

Partial section of Strelna formation in Nugget Creek valley.

	Feet.
Fine-grained basalt	360
Water-laid and subaerial tuff	885
Fine-grained basalt	450
Shaly, argillaceous beds	405
Siliceous beds	10
Fine-grained basalt	450
Silicified limestone	5
Gabbro with some tuffaceous beds	405
Chert	225
Gabbro	650
	3, 845

An unusual phase of the sedimentary rocks appearing possibly to be in the Strelna formation is found in a small area of conglomerate or breccia on the east branch of Nugget Creek. The conglomerate consists essentially of greenstone fragments and boulders 1 foot or less in diameter in a coarse-grained matrix that also consists of greenstone. It is associated with a few beds of hard fissile slate of various colors—gray, dark blue, black, red, and green—and with a soft dirty-white tuff in small irregularly shaped but very conspicuous areas. The stratigraphic relations of these rocks are not known, but it appears more probable that the conglomerate is a faulted mass of rock belonging to the Kotsina conglomerate.

The evidence for the position of the sedimentary beds in the Strelna formation is not complete. The formation is exposed along the northeast and southwest sides of the area mapped, but with the exception of a minor amount of shale and a few thin beds of silicified limestone (see p. 23) rocks of undoubted sedimentary origin are found chiefly on the southwest side. Such a condition suggests a number of possibilities. The sedimentary beds may occupy the middle or the lower part of the formation, or the rocks of the two areas may not be properly correlated, or the equivalent of the sedimentary beds in the southwestern area may be found in the tuffs of the northeastern area.

If the sedimentary beds represent a part of the Strelna formation well below the top of the section, then it seems necessary to suppose that a large part of the sedimentary beds has not been raised to the surface in the northeastern area and that they have been brought into their present position, in contact with or close to the Triassic rocks on Elliott Creek and the Nikolai greenstone on Strelna Creek, by faulting that has cut out the upper part of the formation. Faulting has taken place along the south side of Elliott Creek so as to bring the Strelna rocks into contact with the Triassic limestone and shale, but the conditions east of Strelna Creek are different. There the Nikolai greenstone appears to rest conformably on rocks of the Strelna formation. A section which is believed to include the base of the Nikolai greenstone was examined on a small southward-flowing creek 1 mile east of Strelna Creek (fig. 3).

All the outcrops along the lower part of the creek are altered diorite. The diorite is followed on the north by about 500 feet of black faintly banded rock that appears to be a baked shale and contains thin sandy beds. Over this is 20 feet of thin-bedded chert. Then follow about 75 feet of fine-grained tuffaceous greenstone or altered basalt with pillow structure, 30 feet of thinly bedded chert containing carbonaceous matter, 150 feet more of tuffaceous greenstone with pillow structure, and finally a great thickness of amygdaloidal basalt, the Nikolai greenstone, extending to the top of the mountain.

On the east fork of Strelna Creek the Nikolai greenstone rests on cherty beds associated with thin beds of limestone and with tuffs or shales that contain fossils.

The fine-grained basalts, tuffs, and cherts of the northeastern area, correlated with the Strelna formation, have a structural parallelism with the overlying amygdaloidal basalts (Nikolai) in many places and grade into them so that it is impossible to draw a sharp dividing line between the two formations. Only a small amount of limestone and no fossils were found in these rocks.

If the rocks in these two areas referred to the Strelna formation are not corresponding parts of one series of conformable beds, then

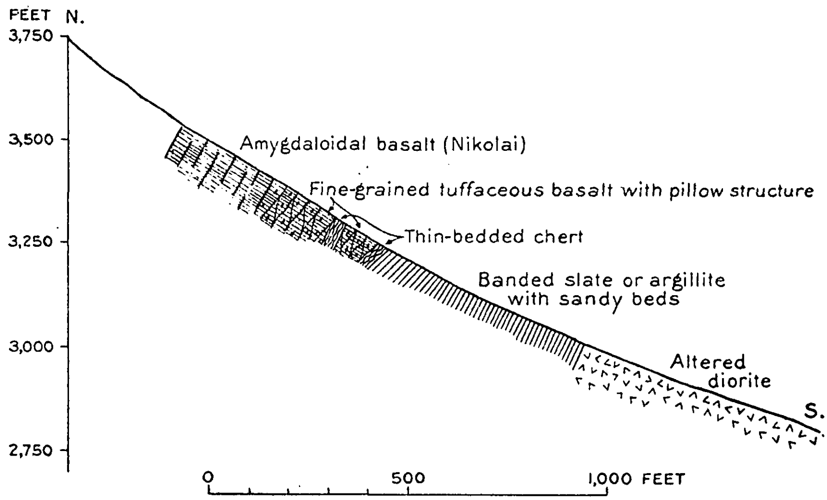


FIGURE 3.—Section at the base of the Nikolai greenstone 1 mile east of Strelna Creek.

it is probable that an unconformity exists at the base of the Nikolai greenstone, that the equivalents of the northeastern rocks are absent on Strelna and Elliott creeks, because they have been faulted out or have been eroded away, and that the tuffs, fine-grained basalts, cherts, limestones, and other members of the Strelna formation in the southwestern area are much older than the tuffs, fine-grained basalts, and cherty beds in the northeastern area.

Evidence for the stratigraphic relations of the Strelna formation and Nikolai greenstone was sought in the places where these relations were likely to be shown, particularly on Kluvesna and Kotsina rivers and on Nugget Creek and the east side of Strelna Creek. On Kluvesna River there is a seeming discordance of structure and, as has been indicated, a variation in the character of rocks immediately below lava flows regarded as belonging to the Nikolai greenstone. The first of these conditions might be due either to faulting or to an original unconformity. The second might result from an unconformity, from failure to determine exactly the position of the boundary line between the two series of rocks, or from local variations in the character of the volcanic and sedimentary materials that were being deposited at a particular time.

In a region of extreme faulting, such as the Kotsina-Kuskulana district, it is difficult to weigh the evidence bearing on the relations of two such series of rocks as the Strelna formation and the Nikolai greenstone. The field evidence in some places indicates structural parallelism, yet in other places discordance of structure and difference in character of beds underlying the greenstone suggest the possibility that the greenstone was poured out over an eroded land surface.

The similarity between the basaltic and tuffaceous rocks underlying the Nikolai greenstone on the two sides of the district is so great that no doubt was felt in the field concerning the equivalence of the rocks in the two areas, although the thick fossiliferous limestones were not seen in the northeastern area. It was recognized, however, that the basic intrusive rocks in the southwestern area were far more abundant and much more altered than those on Kotsina River and Nugget Creek. This was believed to follow from the fact that Strelna and Elliott creeks lie in areas of great disturbance, where folding and faulting have been intense.

The southern boundary of the Triassic rocks of the south side of Elliott Creek is determined by a great fault, but the position of the Nikolai greenstone on the volcanic and associated sedimentary beds on the east side of Strelna Creek is probably not the result of faulting. More likely it represents the original position, which, from the best evidence that was seen in the field, is one of conformity, although that evidence is not conclusive. If this is true, the sedimentary rocks appear to have a considerable range within the Strelna formation, possibly from the middle or lower part to the top. Furthermore, it would appear that part of the sedimentary beds on Strelna Creek and near by are the equivalents of some of the fragmental volcanic rocks of the northeastern area or else are unrepresented there.

THICKNESS AND STRUCTURE.

The thickness of the sedimentary part of the Strelna formation is very much in doubt. Reasons are given on page 60 for regarding the total thickness of the formation as not less than 6,500 feet and possibly as much greater. The thickness of the sedimentary portion, by which is meant the argillites, limestones, and some of the cherts, does not appear to be more than one-tenth or possibly one-eighth of that, although several beds of argillite and a number of limestones, the largest of which is not less than 200 feet thick, are present.

The structure of the beds has been indicated. The members of the formation, particularly those of the southwestern area, are much folded and faulted. In general the rocks of the southwestern area dip toward the northeast. Those in the northeastern area dip southwest under the Nikolai greenstone except in the vicinity of Kuskulana Glacier, where the dip is northeast again, suggesting an anticline with northwesterly axis in the northeastern area.

Faulting and folding in the southwestern area are seen more distinctly in the limestones than in other members of the formation. This is due to the fact that the limestones are more readily identified and traced. The limestone beds have been broken up into numerous isolated areas that apparently have little connection with one another and are scattered about without regularity or order.

AGE AND CORRELATION.

The age determination of the Strelna formation is based on the evidence of fossils collected from the limestones and from some of the tuffs or argillites. Although the fossils are in a poor state of preservation, they show clearly that the rocks containing them are Carboniferous, probably lower Carboniferous (Mississippian). The collections were submitted to George H. Girty for identification, with the result indicated in the following list:

Fossils collected from the Strelna formation.

	8170	8171	8172	8173	Lot 1.	Lot 2.	Lot 3.	Lot 4.	Lot 519.
Zaphrentis sp								×	
Amplexus sp							×		
Crinoid stems		×	×		×	×		×	
Echinoid spines				×					
Fenestelloid Bryozoa					×				
Fenestella sp						×	×	×	
Polypora sp						×	×		
Pinnatopora sp							×		
Lingula sp	×								
Productus semireticulatus						×			
Pustula aff. P. elegans							×		
Pustula aff. P. pustulosa							×		
Pustula sp							×		
Rhipidomella sp							×		
Rhynchonelloid, small (Pugnax?)				×					
Rhynchopora? sp							×		
Dielasma? sp							×		
Terebratuloid (small)				×					
Cliothyridina? sp							×		
Composita? sp									×
Spirifer aff. S. pinguis						×	×		
Spirifer sp								×	×
Euomphalus? sp							×		
Platyceras sp							×		
Phillipsia sp							×		
Griffithides sp								×	

8170 (12AC59). Strelna Creek, east side above main fork. Limestone member of sedimentary series of limestone, shale, conglomerate and cherty siliceous beds. These appear to dip beneath the greenstone and may underlie it or be the lower part of it.

8171 (12AC61). Ridge between forks of Strelna Creek. Cherty limestone beds associated with greenstone.

8172 (12AC66). Ridge south of west fork of Strelna Creek. Limestone, chert, and shale interbedded with greenstone.

8173 (12AC67). West fork of Strelna Creek. Limestone.

Lot 1 (J. B. M. 24). 6,500 feet N. 74° W. from forks of Strelna Creek, elevation 4,700 feet.

Lot 2 (J. B. M. 34). 7,000 feet S. 48° W. from Iron Mountain, elevation 4,000 feet.

Lot 3 (J. B. M. 41). 7,500 feet S. 84° W. from Iron Mountain, elevation 5,300 feet.

Lot 4 (J. B. M. 45). 10,250 feet N. 78° W. from Iron Mountain, elevation 5,700 feet.

Lot 519 (F. H. M. 519). Same as lot 2.

Concerning the fossils found at the last five localities, Mr. Girty says:

The fossils in these collections are in a poor state of preservation. So far as can be determined all the collections represent the same fauna, which is clearly of Carboniferous age. A more definite statement it is difficult to make with certainty, but I am inclined to believe that the horizon is lower Carboniferous (Mississippian) or Lisburne limestone. It is not possible to do more than suggest the character of the fauna in a general way, for accurate specific determinations can not be made from this material.

The Lisburne formation at its type locality consists of massive limestone interstratified with white chert and has a total thickness of more than 2,000 feet. It contains an extensive coral and bryozoan fauna. This formation is well developed in the vicinity of Cape Lisburne and was described first by Collier[9] and later by Kindle.[10] Smith[11] found it also on Noatak River. It was correlated with the limestones of John and Anuktuvuk rivers described by Schrader,[12] and from the work of Leffingwell,[13] Kindle,[14] and Maddren[15] it is known to extend eastward across northern Alaska to the international boundary.

Rocks yielding the fauna of the Lisburne limestone are found on some of the islands of southeastern Alaska[16] and at the head of Chitina River. Probably the Carboniferous fossiliferous rocks of the Strelna formation are to be correlated also with those of Hanagita Valley.[17] The nearness of the two localities would suggest this correlation.

A table showing the principal districts of Alaska where Carboniferous rocks are known appears opposite this page.

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[9] Collier, A. J., Geology and coal resources of the Cape Lisburne region, Alaska: U. S. Geol. Survey Bull. 278, pp. 16–27, 1906.

[10] Kindle, E. M., The section at Cape Thompson, Alaska: Am. Jour. Sci., 4th ser., vol. 28, pp. 520–528, 1909.

[11] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, pp. 75–78, 1913.

[12] Schrader, F. C., Reconnaissance in northern Alaska in 1901: U. S. Geol. Survey Prof. Paper 20, pp. 64–65, 1904.

[13] Leffingwell, E. deK., The Canning River region, northern Alaska: U. S. Geol. Survey Prof. Paper 109, pp. 108–113, 1919.

[14] Kindle, E. M., Geologic reconnaissance of the Porcupine Valley, Alaska: Geol. Soc. America Bull., vol. 19, pp. 315–338, 1908.

[15] Maddren, A. G., Geologic work along the Canada-Alaska boundary: U. S. Geol. Survey Bull. 520, pp. 310–312, 1911.

[16] Kindle, E. M., Notes on the faunas and stratigraphy of southeastern Alaska: Jour. Geology, vol. 15, pp. 330–337, 1907. Wright, F. E. and C. W., The Ketchikan and Wrangell mining districts, Alaska: U. S. Geol. Survey Bull. 347, pp. 52–57, 1908.

[17] Moffit, F. H., Geology of the Hanagita-Bremner region, Alaska: U. S. Geol. Survey Bull. 576, pp. 18–21, 1914.

Carboniferous rocks in Alaska and tentative correlations suggested by the fossils.

	Cape Lisburne (Collier [a]).	Cape Thompson (Kindle [b]).	Noatak River (Smith [c]).	Anaktuvuk and John rivers (Schrader [d]).	Canning and Hulahula rivers (Leffingwell [e]).	International boundary north of Porcupine River (Maddren [f]).	Porcupine River (Kindle [g]).	Upper Yukon (Brooks and Kindle [h]).	Cape Prince of Wales (Collier and others [i]).	Upper Copper River (Mendenhall [j]).	Upper White and Nizina rivers (Capps [k]).	Upper Chitina River (Moffit [l]).	Southeastern Alaska (Kindle [m]).	Yukon-Tanana region (Prindle [n]).	Kotsina-Kuskulana district (this report).
Permian.								Limestone, 200+ feet.		Part of Mankomen formation may belong here.	Limestone.		Limestone, 800 feet.		
Pennsylvanian.						Massive gray limestone, shale and shaly limestone, and shale, 1,500 feet.				Mankomen formation (sandstone, shale, and limestone with much igneous matter), 6,000–7,000 feet.					
		Limestone, 2,000 feet.			Sadlerochit sandstone (light-colored sandstone to dark-colored quartzite).	Shale and shaly limestone, 1,500 feet.	Limestone and shale, 200+ feet.				Limestone, tuff, and shale.		Limestone and carbonaceous shale.		
Mississippian.								Nation River formation (gray shale, clay slate, massive conglomerate, and sandstone), 3,700 feet.							
	Lisburne formation (massive limestone with interstratified white chert beds), 2,000 feet.	Limestone, 3,000 feet.	Lisburne limestone (limestone, locally semicrystalline and siliceous).	Devonian (?) Lisburne formation (semicrystalline limestone of impure white or gray color), 3,000 feet.	Lisburne limestone (limestone), 3,000 feet.	Limestone, shaly limestone, and shale, 4,000 feet.		Calico Bluff formation (black and gray shale with numerous thin beds of limestone and some slate), 900 feet.	Crystalline limestone interbedded with phyllite.			Limestone, grit, and slate.	Limestone, 1,500 feet.	([o]) Greenish, grayish, and black slates.	Strelna formation (tuff beds, dense, fine-grained basalt, argillaceous and sandy shale, chert, and thin limestones).
	Slate, shale, and limestone containing several coal beds.	Shale and sandstone, 420 feet.	Noatak sandstone (sandstone containing a little shale and limestone).	Fickett series (shale, a little limestone, quartzite, grit, and conglomerate).			Shale and thin limestone, 500+ feet.			Chisna formation (conglomerate, quartzite, tuff, and limestone).					

[a] Collier, A. J., Geology and coal resources of the Cape Lisburne region, Alaska: U. S. Geol. Survey Bull. 278, pp. 18–27, 1906.
[b] Kindle, E. M., The section at Cape Thompson, Alaska: Am. Jour. Sci., 4th ser., vol. 28, pp. 520–528, 1909.
[c] Smith, P. S., The Noatak-Kobuk region, Alaska: U. S. Geol. Survey Bull. 536, pp. 69–78, 1913.
[d] Schrader, F. C., A reconnaissance in northern Alaska in 1901: U. S. Geol. Survey Prof. Paper 20, pp. 62–72, 1904.
[e] Leffingwell, E. deK., The Canning river region, northern Alaska: U. S. Geol. Survey Prof. Paper 109, pp. 108–115, 1919.
[f] Maddren, A. G., Geologic work along the Canada-Alaska boundary: U. S. Geol. Survey Bull. 520, pp. 310–312, 1922.
[g] Kindle, E. M., Geologic reconnaissance of the Porcupine Valley, Alaska: Geol. Soc. America Bull., vol. 19, pp. 315–338, 1908.
[h] Brooks, A. H., and Kindle, E. M., Paleozoic and associated rocks of the upper Yukon, Alaska: Geol. Soc. America Bull., vol. 19, pp. 255–338, 1908.
[i] Collier, A. J., Hess, F. L., Smith, P. S., and Brooks, A. H., The gold placers of parts of Seward Peninsula, Alaska: U. S. Geol. Survey Bull. 328, pp. 81–82, 1908.
[j] Mendenhall, W. C., Geology of the central Copper River region, Alaska: U. S. Geol. Survey Prof. Paper 41, pp. 33–36, 1905.
[k] Capps, S. R., The Chisana-White River district, Alaska: U. S. Geol. Survey Bull. 630, pp. 33–47, 1916.
[l] Moffit, F. H., The upper Chitina Valley, Alaska: U. S. Geol. Survey Bull. 675, pp. 18–24, 1918.
[m] Kindle, E. M., Notes on the faunas and stratigraphy of southeastern Alaska: Jour. Geology, vol. 15, pp. 330–337, 1907.
[n] Prindle, L. M., The Fairbanks and Rampart quadrangles, Alaska: U. S. Geol. Survey Bull. 337, p. 22, 1908.
[o] The Rampart group, which probably belongs at this place in the column, was considered by Prindle to be Devonian. The fossils on which this assignment was made have been redetermined by George H. Girty as Carboniferous (upper Mississippian?), and other fossils collected by Overbeck from the same district in 1918 are also assigned by Girty to this age. The rocks that yielded these fossils are believed to be at or just below the base of the Rampart group.

MESOZOIC SEDIMENTARY FORMATIONS.

CHITISTONE LIMESTONE (UPPER TRIASSIC).

CHARACTER AND DISTRIBUTION.

The Chitistone limestone is a marine sedimentary formation that is extensively developed on the north side of Chitina Valley and is a conspicuous feature of the mountains in the Kotsina-Kuskulana district. It forms bold cliffs (Pls. XI, *A*, and XIII, *B*, pp. 30, 31), and its light color is in strong contrast with the dark greenstone, shale, or conglomerate associated with it, so that the formation has been most useful as a horizon marker to all who have studied the geologic structure of the district.

Freshly broken surfaces of the limestone show a bluish-gray color that becomes a lighter gray after the rock has been exposed a long time to the weather. This bluish-gray color is one of the means for distinguishing between the Chitistone limestone and the yellowish-brown weathered limestone of the overlying Kuskulana formation, yet a yellowish weathering is seen on beds that are regarded as belonging in the Chitistone limestone.

The basal part of the Chitistone limestone consists of one or more massive limestone beds showing little or no evidence of stratification. The structure is difficult to determine in this part of the formation, especially where the overlying beds are absent. The upper part, however, is distinctly bedded (Pl. VIII, *A*, p. 6) but is practically without shaly partings, the strata being of the same character as the basal beds and ranging from less than a foot to several feet in thickness. These statements describe the Chitistone limestone on Strelna Creek, where about 400 feet of beds are exposed.

A slightly different section is seen on Clear Creek, where the formation includes possibly 700 feet of bluish-gray limestone. Its lower part is composed principally of massive beds (Pl. X, *B*, p. 30), which make up about three-fourths of the entire thickness. This part is divided into two members by a few thin beds near the top. Fragmentary and poorly preserved fossils were obtained from the thin beds. The upper part of the formation is more thinly stratified, although the massive character of the strata is still maintained.

Although the Chitistone limestone has suffered less folding than the thin-bedded limestone and shale that overlie it, yet it is considerably faulted (Pl. IX, *B*, p. 7) and in places is brecciated. The thin beds in particular show by an intricate system of fine calcite veins the effects of crushing. Nearly all the exposures of the Chitistone limestone contain inclusions of black cherty material in masses of irregular shape and variable size. Some of the cherts are in the form of small veins, but more commonly they have peculiar shapes like flattened and distorted cylinders with knobby protrusions such as might be made by filling the open spaces of a giant sponge with some hard black material. Most of these cherty masses do not exceed 18 inches in greatest diameter.

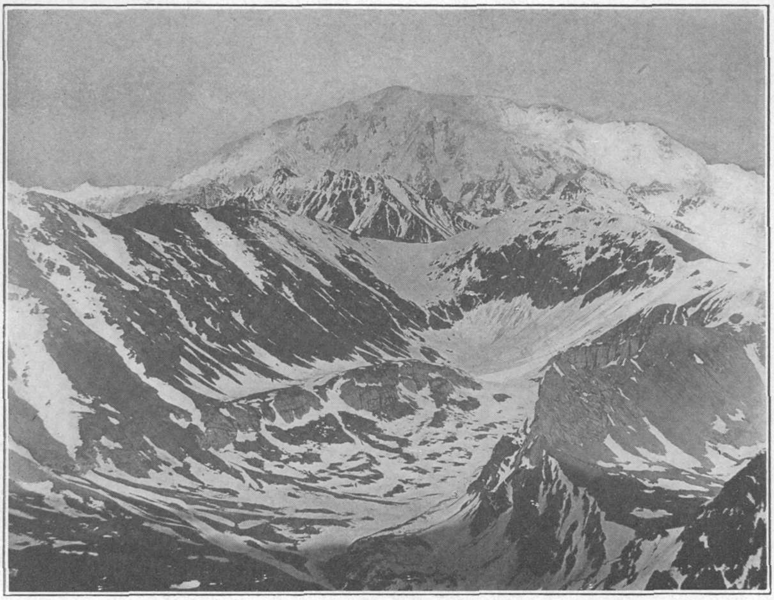
Fossils are rare in the massive part of the Chitistone formation and are so like the limestone surrounding them that they are difficult to find until weathering has freed them from the casts. They are more common in the thin beds of the upper part of the formation, so that a short search is usually sufficient to discover them there.

The principal exposures of the Chitistone limestone form five belts or scarps that have a radial arrangement and extend in an approximate northwesterly direction. The longest and least disturbed of these belts (Pl. VII, p. 6) runs from the mouth of Clear Creek on Kuskulana River to the top of the mountains west of Kluvesna River; the southernmost belt is in the valley of Elliott Creek (Pls. V, *B*; X, *A*; and XI, *A*); and the rest, of less regular outline, lie between (Pl. III, in pocket). The limestone in one of these belts—that which follows the valleys of Pass and Rock creeks—was at first regarded in the field as possibly a second massive limestone within the Kuskulana formation, the chief reasons for this correlation being that the limestone is thinner than the Chitistone limestone on Clear and Lime creeks, although no thinner than on Elliott Creek, and that less of the thin-bedded limestone and shale appears to overlie it at all exposures. This rock, however, is lithologically identical with the basal beds of the Chitistone limestone, carries the Chitistone fauna, and is faulted into its present position on the shale and thin-bedded limestone.

Besides these more or less continuous belts a number of small scattered areas of limestone are present in the district. The largest are near Kuskulana Glacier, on its east side; the others are on Nugget, Roaring, and Pass creeks. They are the remnants of a continuous sheet of limestone that once extended over the whole area. The isolated areas of limestone on Nugget and Roaring creeks appear to be out of their normal position, for they should be separated from the rocks of the underlying Strelna formation by the full thickness of the Nikolai greenstone. They evidently were brought into their present position by faulting, which cut out part of the rocks that normally would underlie the limestone.

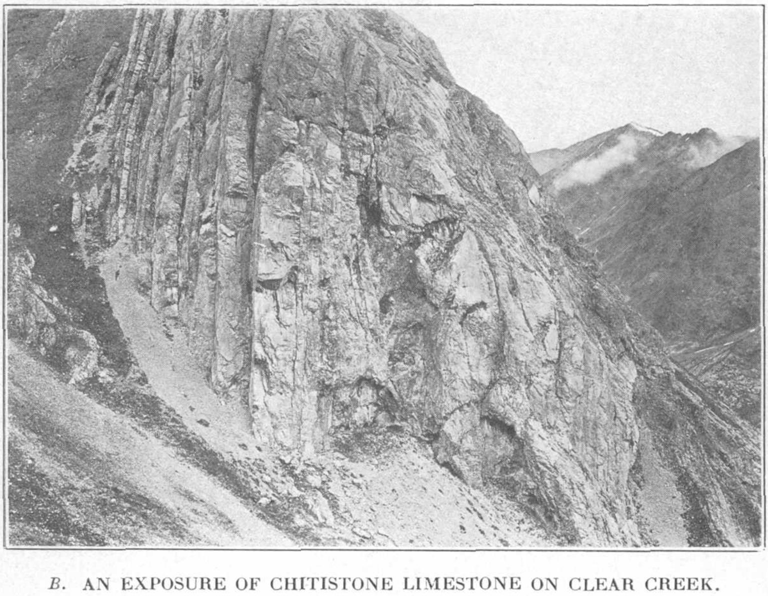
THICKNESS AND STRUCTURE.

The apparent thickness of the Chitistone limestone varies much in certain localities. On the north side of Elliott Creek it ranges from 75 to about 200 feet. On the north fork of Strelna Creek it appears to be not less than 400 feet, but here the difficulty of drawing a definite line between the Chitistone limestone and the overlying thin-bedded limestone of the Kuskulana formation throws doubt on the



A. HEAD OF ELLIOTT CREEK.

Shows the Chitistone limestone scarp encircling the valley. Mount Blackburn in the background.



B. AN EXPOSURE OF CHITISTONE LIMESTONE ON CLEAR CREEK.

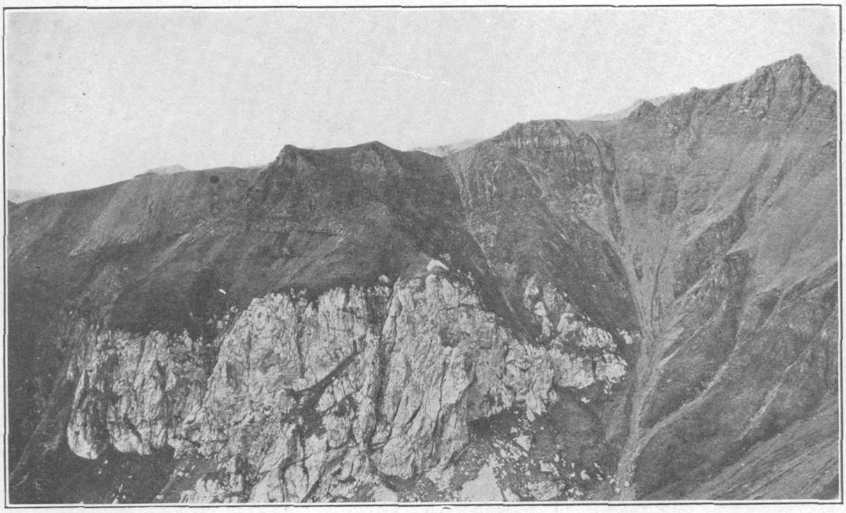
A. SCARP OF THE CHITISTONE LIMESTONE WEST OF DECEPTION CREEK.

A small mass of Nikolai greenstone is faulted over the limestone but is separated from it by conglomerate.

B. THIN LIMESTONE BEDS IN BLACK TRIASSIC SHALE ON STRELNA CREEK NEAR DIXIE PASS.

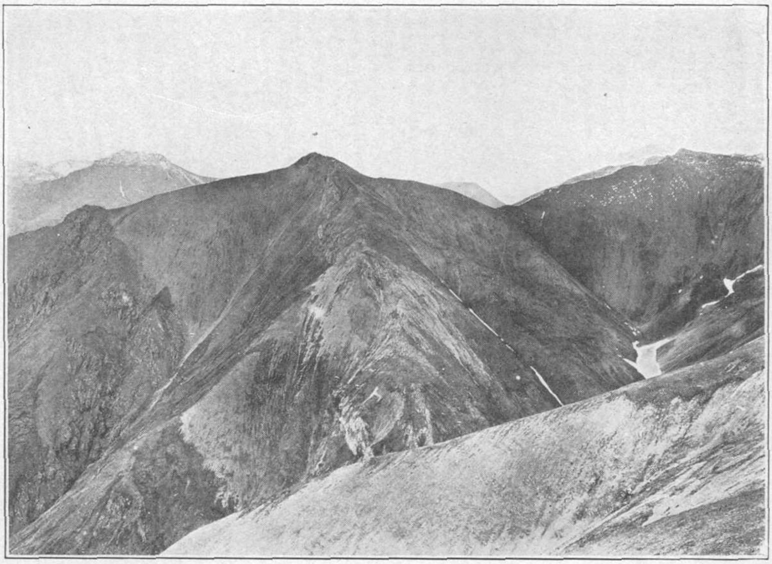
A. VIEW LOOKING DOWN ROCK CREEK AND ACROSS KOTSINA RIVER.

On the right the Chitistone limestone overlies the Nikolai greenstone. In the distant mountain on the left the limestone is repeated by faulting.



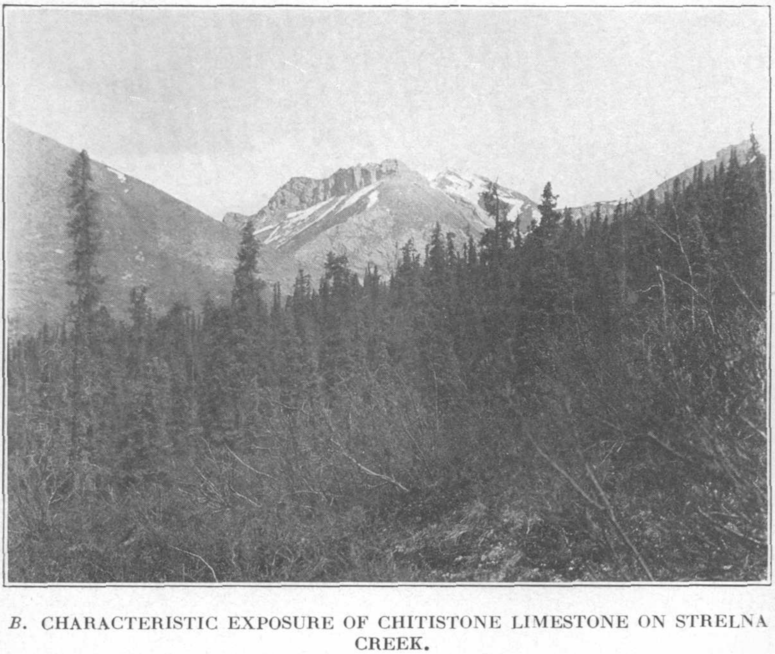
B. NEARER VIEW OF THE DISTANT MOUNTAIN SHOWN IN *A*.

The Chitistone limestone is overlain by Triassic shale, and this in turn by conglomerate.



A. MOUNTAIN BETWEEN THE FORKS OF THE EASTERN BRANCH OF STRELNA CREEK.

The light-colored Chitistone limestone overlies black Triassic shale, which in turn rests on Jurassic conglomerate.



B. CHARACTERISTIC EXPOSURE OF CHITISTONE LIMESTONE ON STRELNA CREEK.

Below the limestone is greenstone.

accuracy of the measurement. At this locality the limestone stands on edge and strikes about N. 45° W. The massive basal beds on the southwest are 200 feet thick. They are followed on the northeast by 200 feet of thinner beds that are considered to belong in the Chitistone, and these in turn are followed by thin-bedded limestone with a small amount of interstratified shale that may belong to the Kuskulana formation, but the exact position of the boundary line between the last two appears to be a matter of individual judgment. On Clear Creek the thickness of the Chitistone limestone can be measured with considerable accuracy at several places. The beds dip to the west without minor folds and indicate a thickness of 700 feet. A thickness of 700 or possibly 1,000 feet is indicated at the head of Lime Creek. On both streams the most uncertain factor in this measurement is the position of the horizon that marks the top of the Chitistone limestone.

The Chitistone limestone in its type locality, opposite the mouth of Chitistone River, in the Nizina district, was considered by Moffit and Capps[18] to have a thickness of 3,000 feet.

For lithologic reasons the upper 1,200 feet of yellow-weathering, thin-bedded limestone in this section might be assigned to an overlying formation, as has been done by Martin,[19] although this assignment can not yet be confirmed by the evidence of fossils. In spite of so great a reduction in thickness as this division would mean, it is evident that the Chitistone limestone on Nizina River is much thicker than in the Kotsina-Kuskulana district. An even more striking difference in thickness is seen within the district itself. Along the north side of Elliott Creek less than 100 feet of the limestone appears between the greenstone and shale in some places. It is this small thickness of the Chitistone limestone and the absence of the overlying thin-bedded limestone that led Martin to assume an unconformity immediately below the McCarthy shale in this district. The possibility of this unconformity is considered in the description of the rocks overlying the Chitistone limestone (p. 37).

Folding and faulting give the Chitistone limestone a complicated structure. So far as is known from the evidence collected, the limestone was deposited conformably on the Nikolai greenstone. Movement has taken place along the contact of the two formations in many localities, but no positive evidence of an extended interval of erosion between the pouring out of the Nikolai lavas and the deposition of the Chitistone limestone has been recognized in the field, although from

[18] Moffit, F. H., and Capps, S. R., Geology and mineral resources of the Nizina district, Alaska: U. S. Geol. Survey Bull. 448, p. 23, 1911.

[19] Martin, G. C., Triassic rocks of Alaska: Geol. Soc. America Bull., vol. 27, p. 690, 1916.

other considerations the occurrence of such a break might be suspected.

The three northern belts of the Chitistone limestone dip at rather high angles to the southwest (Pls. VII and XII, *A*, pp. 6, 30). The northernmost belt lies on the Nikolai greenstone in its normal position, but the other two belts owe their positions to faulting, which thrust them over beds that normally would rest on them.

The two limestone belts on Elliott Creek and the west branch of Strelna Creek are the limbs of anticlines (Pl. X, *A*, p. 30), whose crests have been eroded away. Faulting along the south side of Elliott Creek cut out the Kuskulana formation in places and brought the limestone into contact with rocks of the Strelna formation. The limestone on the north side of Elliott Creek dips north (Pl. V, *B*, p. 6) and reappears on Copper and Pass creeks, forming a synclinal trough in which lies a great mass of Kotsina conglomerate.

The Chitistone is cut by many other faults besides the major ones already mentioned. Some of these are shown on the map. The area about the head of Elliott Creek and the west fork of Strelna Creek was subjected to an exceptional amount of disturbance of this kind, so that blocks of the different formations have been brought into a most confusing complex.

INTRUSIVE ROCKS.

Igneous rocks intruded into the Chitistone limestone are not common. No large masses of igneous rock were seen in the formation, and although a few dikes were found, they and the sills associated with them are far more numerous in the overlying shale and in the Kotsina conglomerate than in the limestone. It appears to have been more difficult for the molten rock to penetrate the limestone than the shale or even the massive conglomerate, and although it must have been necessary for the intrusives to cut the Chitistone limestone in order to reach the overlying beds in places where the limestone had not been removed by erosion, only a few such places were discovered. The possibility of the sills having been intruded at different times is considered on page 73.

Dikes of granodiorite, apophyses of the larger mass near by, cut the Chitistone limestone at the mouth of Pass Creek. Dikes of quartz diorite porphyry with phenocrysts of feldspar are intruded into the limestone west of Kluvesna River. They are associated at the same locality with dikes of porphyritic basalt containing long crystals of either hornblende or pyroxene. Near the mouth of Clear Creek, a tributary of Kuskulana River, a tabular body of basalt porphyry about 100 feet thick intrudes the limestone. For the most part it follows the bedding planes of its host, but in places it cuts across the beds. Columnar structure is well developed in this basalt. A small dike of similar rock cuts the limestone-greenstone contact near the head of Clear Creek. It is easily distinguished from the greenstone in places where the greenstone shows a reddish color but is hard to recognize where the greenstone assumes its normal appearance.

The intrusives in the Chitistone limestone have not produced any pronounced alteration in the inclosing rock. Recrystallization, marmarization, and contact-metamorphic effects were not seen. The molten rock was forced into the limestone along planes of fracture that crossed the bedding or along the bedding planes themselves and there solidified without bringing about conspicuous chemical or physical changes in the limestone.

AGE AND CORRELATION.

The Chitistone limestone is of Upper Triassic age. Fossils, although not abundant, have been found in it at many places in the Chitina Valley, from Kotsina River to the Nizina district. The following list shows the fossils collected in the Kotsina-Kuskulana district:

Fossils collected from the Chitistone limestone in the Kotsina-Kuskulana district.

	2149	4805 (3-6)	4805 (2.23)	4806	8148	8152	8159	8164	8165	8166
Terebratula		×								
Spiriferina		×								
Halobia?						×	×	×	×	×
Gryphaea??							×			
Hinnites?		×								
Hinnites? cf. Halobia occidentalis Whiteaves	×		×							
Pleuromya?		×								
Undetermined pelecypods				×						
Natica?				×						
Undetermined gastropods						×				
Tropites?					×					
Arcestes						×				
Undetermined ammonites			×							

	8167	8923	8925	8931	8932	8938	8946	9919	9929	9946
Corals? (large radiating masses, inorganic?)							×			
Terebratula							×			
Avicula							×			
Halobia cf. H. superba Mojsisovics					×			×	×	×
Halobia sp									×	
Halobia?		×		×	×	×				
Do							×	×		
Gryphaea??	×	×					×			
Myophoria (2 or more species)							×			
Myophoria?						×				
Pecten		×								
Pecten? (large coarse-ribbed species)				×						
Pleuromya							×			
Turbo?							×			
Pseudomelania?							×			
Natica?				×						
Undetermined gastropods						×				
Arcestes?			×							
Undetermined ammonites		×						×		

2149. Near pass between head of Pass Creek and Rock Creek. From talus just under reef of heavy-bedded limestone. F. C. Schrader, 1900.

4805 (3-6). Talus from lower 200 feet of Chitistone limestone on Copper Creek. Moffit and Maddren, 1907.

4805 (2, 23). Hoodoo or Mullen claim on Copper Creek, about 200 feet above base of Chitistone limestone. Moffit and Maddren, 1907.
4806. Crawford's Skyscraper claim on Roaring Creek from lower 100 feet of Chitistone limestone. Moffit and Maddren, 1907.
8148. North fork of Strelna Creek on east side of first large creek near its mouth, from upper part of Chitistone limestone (?). F. H. Moffit, 1912.
8152. Clear Creek, blue limestone above roadhouse. Theodore Chapin, 1912.
8159. Clear Creek, from talus slope below the Chitistone and the overlying thin-bedded limestone of the Kuskulana formation. Theodore Chapin, 1912.
8164. Clear Creek. Theodore Chapin, 1912.
8165. Nugget Creek near forks, from fault block of Chitistone limestone. Theodore Chapin, 1912.
8166, 8167. Divide between Nugget and Roaring creeks. Theodore Chapin, 1912.
8923. West side of Lime Creek valley at elevation 4,900 feet. Moffit and Mertie, 1914.
8925. 8,200 feet S. 67° E. from forks of east fork of Strelna Creek, elevation 4,500 feet. F. H. Moffit, 1914.
8931. About 6,600 feet N. 44° E. of Dixie Pass, elevation 5,500 feet. F. H. Moffit, 1914.
8932. About 5,850 feet N. 31° W. from Ammann's cabin on Kluvesna River. F. H. Moffit, 1914.
8938. About 11,800 feet S. 80½° E. from Alice Peak, elevation 4,800 feet. F. H. Moffit, 1914.
8946. South fork of Rock Creek on trail leading to west fork of Strelna Creek, elevation 4,800 feet, probably from thin plate of Chitistone limestone. G. C. Martin, 1914.
9919. North fork of Strelna Creek near bench mark 3664.
9929. North branch of east fork of Strelna Creek.
9946. Dixie Pass branch of Strelna Creek.

It is important to note that *Pseudomonotis subcircularis*, which appears in previous lists of fossils belonging in the Chitistone limestone, is here omitted. Martin [20] sets forth reasons for considering this particular fossil to be characteristic of the McCarthy shale, which is also of Upper Triassic age and, in the Nizina district at least, seemingly followed the Triassic limestones without a break of any kind other than the changed conditions that brought about the deposition of interstratified limestone and shale beds and finally of shale instead of limestone alone.

Schrader and Spencer [21] did not determine the age of the Chitistone limestone from paleontologic evidence during their reconnaissance in 1900 and correlated it with the massive limestone of White River, which was regarded by Schuchert to be of "Upper Carboniferous" age.[22] This correlation was questioned by Mendenhall,[23] but it was not till 1907 that definite evidence of the age of the Chitistone limestone was obtained.[24]

A table of correlations of the Mesozoic formations of southern and southwestern Alaska, compiled by Martin,[25] but with some additions, is given opposite this page.

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[20] Op. cit., p. 712.
[21] Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, p. 46, U. S. Geol. Survey special publication, 1901.
[22] Brooks, A. H., A reconnaissance from Pyramid Harbor to Eagle City, Alaska: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, p. 359, 1900.
[23] Mendenhall, W. C., Geology of the central Copper River region, Alaska: U. S. Geol. Survey Prof. Paper 41, p. 43, 1905.
[24] Moffit, F. H., and Maddren, A. G., Mineral resources of the Kotsina-Chitina region, Alaska: U. S. Geol. Survey Bull. 374, p. 28, 1909.
[25] Martin, G. C., Geology and mineral resources of Kenai Peninsula, Alaska: U. S.
[20] Op. cit., p. 712.

Correlation of formations in southern and southwestern Alaska.

Age.[a]	Western part of Alaska Peninsula (Atwood [b]).	Cook Inlet and Alaska Peninsula (Stanton and Martin [c]).	Iliamna region (Martin and Katz [d]).	Alaska Range (Brooks [e]).	Headwaters of Gulkana and Susitna rivers (Moffit [f]).	Matanuska Valley (Martin and Katz [g]).	Kenai Peninsula.[a]	Prince William Sound (Grant and Higgins; Capps and Johnson [h]).	Hanagita-Bremner region (Moffit [i]).	Chitina Valley (Moffit and others [j]).	Nizina Valley (Martin [k]).	Kotsina-Kuskulana district (Moffit, this report).	
Quaternary.	Clay, sand, gravel, and glacial drift.		Recent volcanic material. Beach and flood-plain deposits. Terrace gravels. Glacial deposits.	Silts, sands, and gravels. Terrace silts, sands, and gravels.	Stream gravels, sands, and silts. High bench gravels and glacial deposits.	Alluvium. Terrace gravels. Morainic deposits.	Alluvial and beach deposits. Glacial and terrace gravels.			Volcanic deposits.			
Tertiary.	Tuffs, agglomerates, breccias, and flows. Unga formation (clay, sandstone, and conglomerate). Kenai formation (shale, sandstone, and conglomerate). Basaltic flows, breccias, agglomerates, and tuffs.	Kenai formation.	Basaltic flows and tuffs. Sedimentary beds.	Kenai formation.	Unconsolidated sands and gravels with lignite deposits. Sandstone, shale, and conglomerate with lignitic coal beds.	Basaltic lavas, breccias, and tuffs. Eska conglomerate. Chickaloon formation (coal-bearing shale and sandstone). Arkose, conglomerate, and shale.	Kenai formation.			Lavas.			
Upper Cretaceous.	Chignik formation (conglomerate, sandstone, and shale).	Shale, sandstone, and conglomerate at Chignik.				Shale and sandstone.							
Lower Cretaceous.	Herendeen limestone (arenaceous limestone). Staniukovich shale (shales with thin beds of sandstone).	Beds with *Aucella crassicollis* at Herendeen Bay.				Limestone with *Aucella crassicollis.*	See slate and graywacke below.	See Orca group below.					
Upper Jurassic.	Naknek formation (sandstone, conglomerate, and arkose).	Naknek formation: Shale with *Aucella pallasi.* Naknek formation: Conglomerate. Enochkin formation: Shale with *Cadoceras.*	Naknek formation. Chisik conglomerate Chinitna shale.			Shale, sandstone, and conglomerate, with *Aucella bronni.* Conglomerate. Beds with *Cadoceras.*	See slate and graywacke below.	See Orca group below.		Kennicott formation (conglomerate, sandstone, limestone, and shale).		Light-colored limestone. Conglomerate, sandstone, and shale. Kotsina conglomerate.	Upper Jurassic.
Middle Jurassic.		Enochkin formation: Sandstone with *Inoceramus ambiguus* and *Trigonia doroschini.*	Tuxedni sandstone.	Tordrillo formation (cut by granite).		Sandstone and shale with *Inoceramus.*			Tuffaceous slate. Tuffaceous conglomerate.				
Lower Jurassic.		Tuffs and cherty limestone at Port Graham and Seldovia.	Porphyries and tuffs.	Skwentna group (cut by granite).		Volcanic breccias, agglomerates, and tuffs, with *Trigonia.*	Fossiliferous tuffs and agglomerate.						
Lower Jurassic (?)		Shales and sandstones above known Triassic at Cold Bay.											
Upper Triassic.		Chert, shale, and limestone with *Pseudomonotis.*	Kamishak chert. Limestone.		Shale, sandstone, slate, arkose, limestone, tuffs, and lava flows. Contain *Halobia* and *Pseudomonotis.*		Chert. Limestones and tuffs.			McCarthy shale (shales) and thin limestone. Chitistone limestone.	McCarthy formation. Nizina limestone. Chitistone limestone.	Kuskulana formation. Chitistone limestone.	Upper Triassic.
Triassic (?) or Carboniferous (?).			Greenstone.		Basic lava flows, tuff, and tuffaceous conglomerate.	Graywacke and slate of Knik River (including basaltic greenstones, rhyolites, and tuffs).	Ellipsoidal lavas.	Orca group[l] (greenstones, slates, etc., probably including Jurassic or Cretaceous beds of undetermined horizon).	Valdez group (slate and graywacke [m]).	Nikolai greenstone.	Nikolai greenstone.	Nikolai greenstone.	Permian or Triassic.
Paleozoic (?) or Mesozoic (?).			Slate and chert.										
Paleozoic.			Crystalline limestone and schist. Gneiss and quartzitic schist.	Limestone (Middle Devonian). Tonzona group (Silurian or Devonian). Tatina group (Ordovican). Birch Creek schist.	Slate, tuff, quartzite, and limestone (Carboniferous). Schists and greenstones (pre-Carboniferous?). Birch Creek schist.	Mica schists and other schistose and gneissic rocks.	Slate and graywacke, including some probably infolded Jurassic or Cretaceous beds of undetermined horizon. (The Sunrise group of earlier reports is probably at least in part here represented.) Schists and crystalline limestone.	Valdez group[l] (slate and graywacke).	Carboniferous (?) slate, schist, and interbedded limestone.			Strelna formation (tuffs, basalt, argillite, chert and limestone).	Mississippian.

[a] Martin, G. C., Geology and mineral resources of Kenai Peninsula, Alaska: U. S. Geol. Survey, Bull. 587, facing p. 32, 1915.
[b] Atwood, W. W., Geology and mineral resources of parts of the Alaska Peninsula: U. S. Geol. Survey Bull. 467, 1911.
[c] Stanton, T. W., and Martin, G. C., Mesozoic section on Cook Inlet and Alaska Peninsula: Geol. Soc. America Bull., vol. 16, pp. 391-410, 1905.
[d] Martin, G. C., and Katz, F. J., A geologic reconnaissance of the Iliamna region, Alaska: U. S. Geol. Survey Bull. 485, 1912.
[e] Brooks, A. H., The Mount McKinley region, Alaska: U. S. Geol. Survey Prof. Paper 70, 1911.
[f] Moffit, F. H., Headwater regions of Gulkana and Susitna rivers, Alaska: U. S. Geol. Survey Bull. 498, 1912.
[g] Martin, G. C., and Katz, F. J., Geology and coal fields of the lower Matanuska Valley, Alaska: U. S. Geol. Survey Bull. 500, 1912.
[h] Grant, U. S., and Higgins, D. F., Reconnaissance of the geology and mineral resources of Prince William Sound, Alaska: U. S. Geol. Survey Bull. 443, pp. 20-33, 1911: Capps, S. R., and Johnson, B. L., Mineral deposits of the Ellamar district: U. S. Geol. Survey Bull. 542, pp. 86-124, 1913
[i] Moffit, F. H., Geology of the Hanagita-Bremner region, Alaska; U. S. Geol. Survey Bull. 576, pp. 17-42, 1914.
[j] Moffit, F. H., and Maddren, A. G., Mineral resources of the Kotsina-Chitina region, Alaska: U. S. Geol. Survey Bull. 374, 1909; Moffit, F. H., and Capps, S. R., Geology and mineral resources of the Nizina district, Alaska: U. S. Geol. Survey Bull. 448, 1911; Moffit, F. H., The upper Chitina Valley, Alaska: U. S. Geol. Survey Bull. 675, pp. 18-45, 1918.
[k] Martin, G. C., Triassic rocks of Alaska: Geol Soc. America Bull., vol. 27, pp. 685-718, 1916.
[l] The age assignments and correlations are those of G. C. Martin (U. S. Geol. Survey Bull. 587, 1915).
[m] The age of the Valdez group and its relations to the Orca group are still undetermined. The Valdez group has generally been regarded as older than the Orca group.

KUSKULANA FORMATION (UPPER TRIASSIC).

CHARACTER AND DISTRIBUTION.

The Chitistone limestone is overlain by probably 5,000 feet of Upper Triassic marine sedimentary strata consisting of black shale and considerable but varying amounts of thin-bedded limestone and argillite, which are best developed at the base of the formation. These strata are equivalent to the Nizina limestone and the McCarthy shale of the Nizina district, but because of their complicated folding and the difficulty of making the separation they were not mapped as two formations, being here described under the term Kuskulana formation, though it is realized that future work may result in dividing the rocks into the two formations just named. It is doubtful if the separation can be made in the west end of the Chitina Valley on any other basis than the evidence of fossils, for the lithologic differences are not sufficient to make the separation possible where the beds are so intricately folded into one another as is common in the Kotsina-Kuskulana district. It might be asserted with reason that a separation of the shale and argillite from the thin-bedded limestones would be more logical than that of the limestone from the underlying Chitistone limestone, and this would undoubtedly be true except for the physical difficulties.

The shale is a black fissile rock nearly everywhere much folded and otherwise disturbed and nowhere without more or less impure limestone in thin beds (Pl. XI, *B*, p. 30). In some places it rests on the Chitistone limestone, but in others it is separated from the Chitistone by a variable thickness of thin-bedded limestone overlain by alternating thin beds of impure limestone or argillite and shale. Dikes and sills of light-colored intrusive rock are common in the shale at a number of localities.

The thin-bedded limestone at the base of the formation, adjacent to the Chitistone beds, is bluish gray but alters to a brownish yellow after it has been exposed to weathering. It becomes impure in the higher beds as the shale makes its appearance and changes its color from bluish gray to black. Where the impurities are most abundant the limestone changes to hard black argillite or calcareous argillite without distinct cleavage, but nowhere in the Kotsina-Kuskulana district are the limestone or argillite beds replaced by chert beds, as they are in Chokosna and Lakina River valleys and in the Nizina district.

The thickness of the limestone beds ranges from less than a foot to 2 or 3 feet but is more commonly less than 2 feet. These figures apply to the limestone beds near the base of the formation where shale is absent, as well as to the higher beds where limestone and shale are interstratified. These limestone-shale beds are more extensively developed than the thin limestones below, and in most of them the limestone predominates over the shale.

The thin-bedded limestone is not a constant member of the formation. In a few places it is practically absent; in others it constitutes a large proportion of the known thickness of the Kuskulana formation. The bluish-gray Chitistone beds of Lime Creek, where the section appears to be least disturbed, are succeeded by brown-weathering thin-bedded limestone without shale in its lower part except possibly in the form of thin partings. Higher in the series the limestone becomes more and more impure, and shale beds in increasing amount make their appearance between the limestone strata (Pl. XVIII, *A*, p. 38). A little higher the shale predominates over the limestone (Pl. XVIII, *B*) and finally replaces it almost altogether (Pl. XI, *B*, p. 30). Practically the same condition is seen on Clear Creek. West of Rock Creek, however, the thin-bedded limestone rests upon the Chitistone beds, just as on Lime Creek, but is much reduced in thickness and gives place more rapidly to the shale. This part of the formation is much folded. The thin limestone beds are contorted and broken and displaced by faulting.

Farther west, on Pass, Copper, and Elliott creeks, the thin limestones are still more reduced in number. In some localities they are practically absent, but there is reason for suspecting that this absence is due in part if not wholly to faulting. Thin beds of limestone are seen in the black shales at different horizons but are almost negligible in comparison with their abundance lower in the formation.

Previous workers in Chitina Valley have based divisions of the Upper Triassic sediments on lithologic differences alone, for the evidence furnished by fossils collected in this region was not such as to lead the paleontologists to suggest the establishment of formations on other grounds. For this reason all the Triassic limestone of the Nizina district was mapped by Moffit and Capps[26] as belonging to the Chitistone limestone, and about 300 feet of thin-bedded limestone and shale, regarded as a transition zone, were included in the overlying McCarthy shale.

Martin,[27] who has made an extended investigation of the Mesozoic rocks of Alaska and spent part of the summer of 1914 in studying the Mesozoic section of Chitina Valley, has reached the conclusion that the Upper Triassic sediments of this valley should be divided into three formations—the Chitistone limestone, consisting of the lower 1,800 feet of that formation as mapped by Moffit and Capps in the type locality near the mouth of Chitistone River; the Nizina

[26] Moffit, F. H., and Capps, S. R., Geology and mineral resources of the Nizina district, Alaska: U. S. Geol. Survey Bull. 448, pp. 21–30, pl. 2, 1911.

[27] Martin, G. C., Triassic rocks of Alaska: Geol. Soc. America Bull., vol. 27, No. 4, pp. 685–718, 1916.

limestone, thin-bedded yellowish-weathering limestone including the upper 1,200 feet of the limestone near the mouth of Chitistone River; and the McCarthy shale. Martin separates the Chitistone from the Nizina limestone on the basis of a slight chemical difference, indicated by the yellowish weathering of the Nizina, and the thickness of the beds, which commonly is greater in the Chitistone limestone. The fauna of the two formations is the same. On the other hand, the separation of the thin-bedded limestone from the overlying McCarthy shale is considered to rest on a paleontologic as well as a lithologic basis, the distinguishing fossil of the shale being *Pseudomonotis subcircularis.*

The three formations show no structural unconformity in the Nizina district, but as interpreted by Martin the equivalent of the McCarthy shale in the Kuskulana formation of the Kotsina-Kuskulana district lies unconformably on the Chitistone and the overlying thin-bedded limestone. This unconformity is assumed in order to account for the variable thickness of the Chitistone limestone and of the thin-bedded limestone and shale. This variation is most noticeable on the north side of Elliott Creek, where the thickness of the Chitistone limestone included between the Nikolai greenstone and the Triassic shale is reduced at one place to about 75 feet. A period of erosion just before the deposition of the McCarthy shale might account satisfactorily for variation in the thickness of the underlying Nizina and Chitistone limestones (the Chitistone limestone and the lower part of the Kuskulana formation of the Kotsina-Kuskulana district), but other causes sufficient to account for the variation have affected the rocks involved.

It seems probable that an unconformity of such magnitude would have left other clear evidence of its existence, such as discordance of structure, basal conglomerate or sandy beds, or indications of an old weathered land surface, in addition to variations in thickness of beds that are not known to have been without variations when originally deposited. No such evidences of unconformity have been observed in the Chitina Valley, but wherever the sections are best the whole succession of beds from the base of the Chitistone limestone to the top of the McCarthy shale appear to have followed one another in orderly succession. If a period of erosion intervened at any time the older beds must have been undisturbed by folding or tilting when the deposition of sediments was resumed, for otherwise discordance of structure would have resulted.

The lowest *Pseudomonotis*-bearing beds between Kotsina and Nizina rivers are thinly stratified impure limestone or argillite, commonly with shale partings. The shale deposits without thin limestone and argillite or with only subordinate beds of that kind are in the upper part of the McCarthy shale and not at the base.

The Chitistone limestone of Elliott and Copper creeks is the massive basal part of the formation and is overlain by black shale apparently belonging in the middle or upper part of the *Pseudomonotis*-bearing beds, for the shale in places lacks the limestone and argillite strata and elsewhere contains only a minor amount of them. Either the base of the shale formation here is unlike the base on Rock Creek and the head of Pass Creek or the lower beds are absent. The latter alternative is believed to be true. The rocks of the southwest side of the Kotsina-Kuskulana district are extensively faulted. Movement has certainly taken place along the contact of the Nikolai greenstone and the Chitistone limestone in places on the north side of Elliott Creek, and the field observations indicate faulting above the limestone on both sides of the creek. If this is true it seems unnecessary to postulate an unconformity in addition.

In the writers' opinion the evidence so far collected for an unconformity within the Upper Triassic sediments of the Kotsina-Kuskulana district is not sufficient to be convincing, although it is sufficient to demand consideration. Future work may show that the erosion took place, although the evidence is probably obscured, for the upper beds of the Triassic sediments, because of their lack of strength, were disturbed most by folding and faulting.

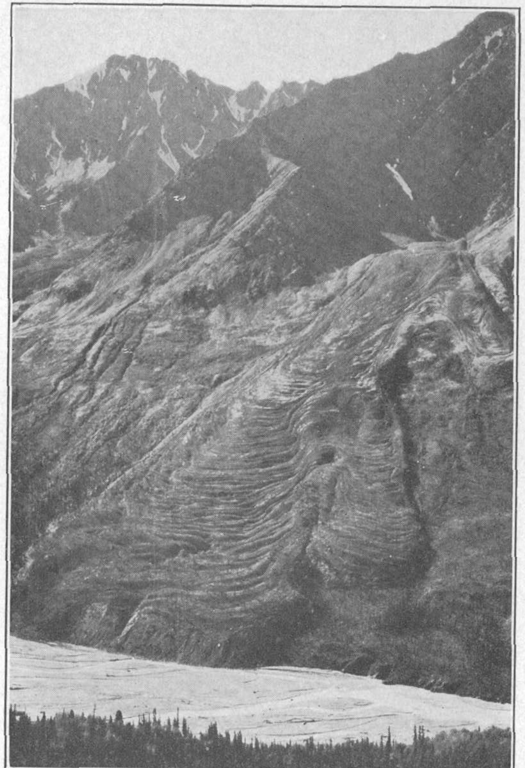
The principal exposures of the Kuskulana formation are seen in a broad belt, or rather two belts, separated by a narrow scarp of Chitistone limestone, extending in a northwesterly direction through the middle of the district (Pl. III, in pocket). These belts, together with the areas on Elliott Creek, include all of the Kuskulana formation within the district except two small areas east of Kuskulana River.

THICKNESS AND STRUCTURE.

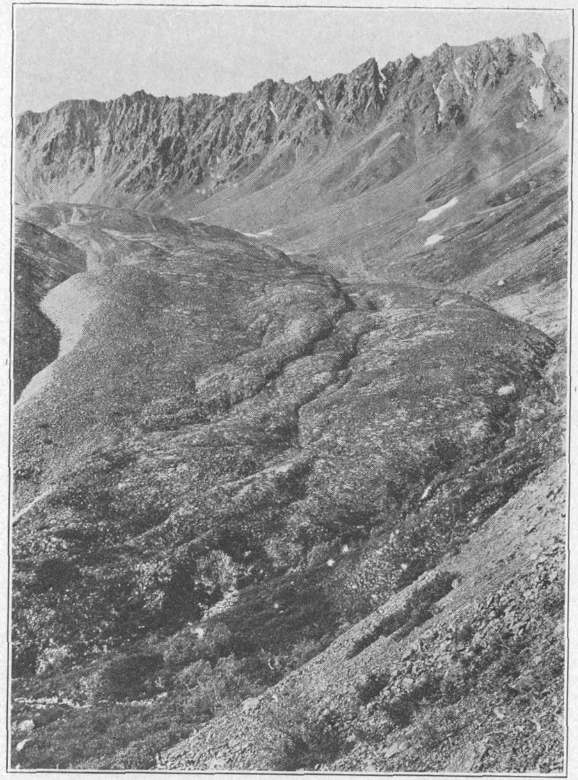
Estimates of the thickness of the Kuskulana formation within the Kotsina-Kuskulana district involve much uncertainty, for the top of the formation has not been recognized and may not be present, the base has not been definitely determined, and the beds, especially those higher in the formation, were subjected to deformation and are much folded.

A measurement made on Rock Creek, where the uncertain factors appear to be less uncertain than at other localities, gives a thickness of about 2,000 feet for the part of the formation that has not undergone close folding, included between the outcrops of the Chitistone limestone on Lime and Rock creeks. The closely folded beds near the creek are not included in this measurement. This figure indicates a minimum rather than a maximum thickness, for it is probable that a considerable thickness of black shale should be added.

The belt of Kuskulana rocks southwest of Lime Creek and that southwest of the narrow belt of Chitistone limestone along the upper part of Rock Creek, although intensely folded in places, show a prevailing dip



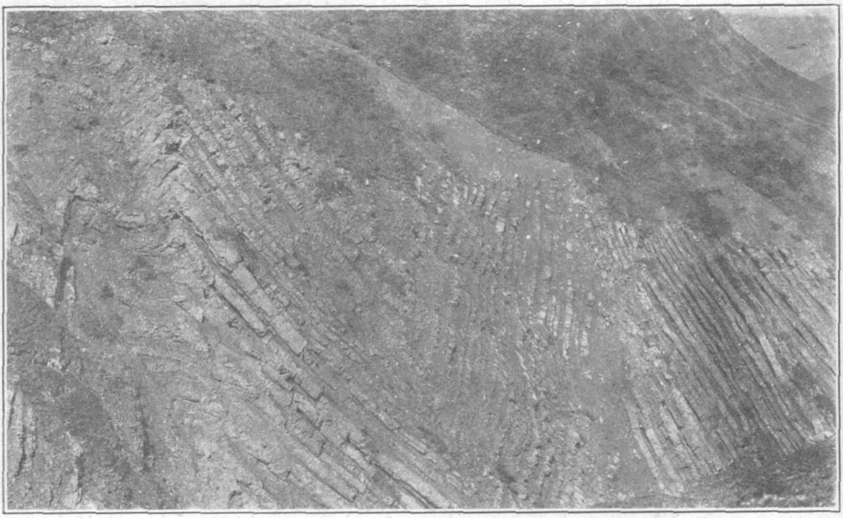
A. "ROCK GLACIER" BETWEEN ROCK AND ROARING CREEKS, ON THE SOUTH SIDE OF KOTSINA RIVER.



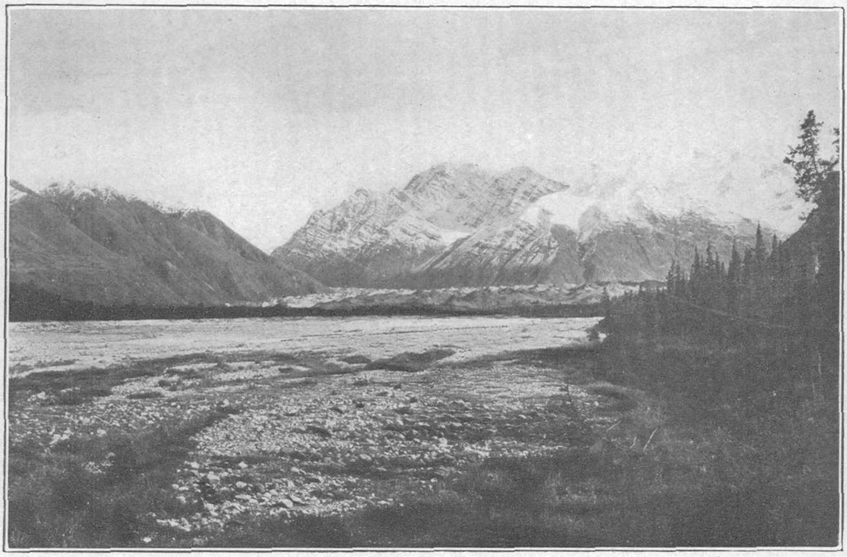
B. "ROCK GLACIER" ON PORCUPINE CREEK.

A more distant view is shown in Plate XVII, *A*.

A. THIN-BEDDED LIMESTONE, ARGILLITE, AND SHALE ON THE WEST SLOPE OF THE RIDGE BETWEEN LIME AND ROCK CREEKS.

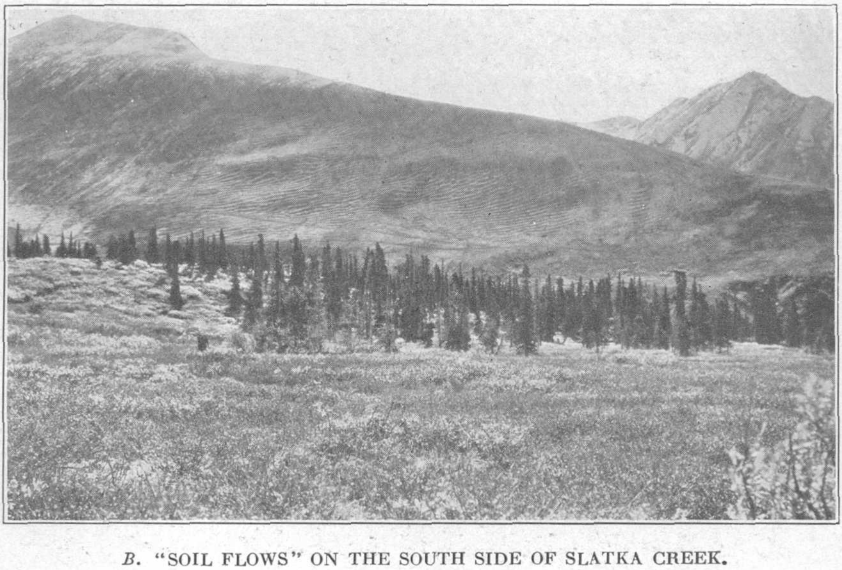


B. FOLDED THIN-BEDDED ARGILLITE AND SHALE ON ROCK CREEK.



A. HEAD OF KUSKULANA RIVER.

Showing the moraine-covered terminus of the glacier and the bedded character of the Nikolai greenstone, partly snow covered.

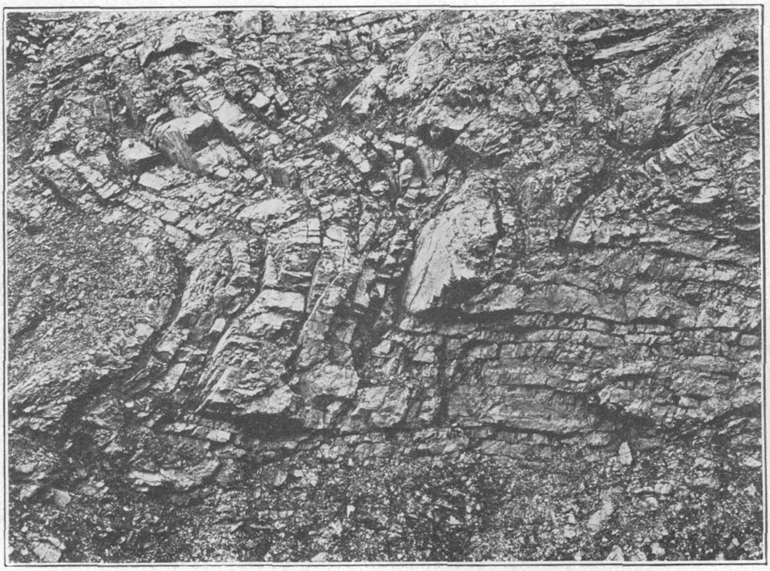


B. "SOIL FLOWS" ON THE SOUTH SIDE OF SLATKA CREEK.

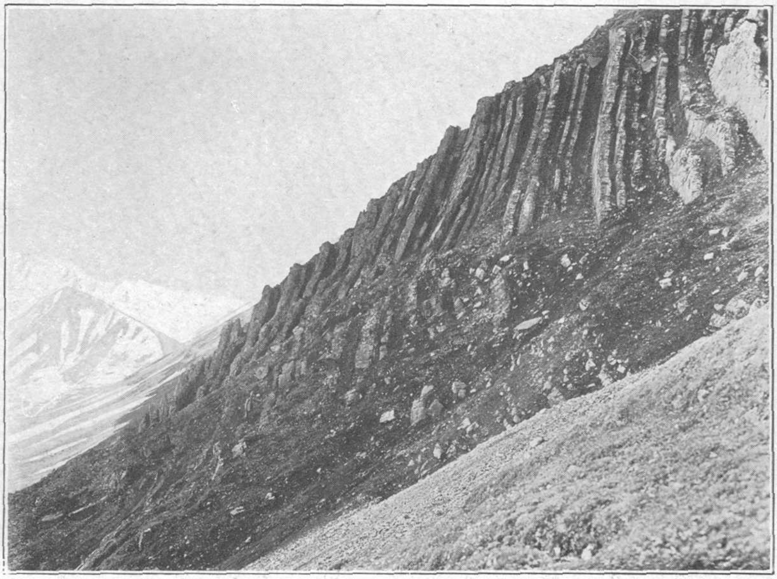
The mountain slope is covered with small angular fragments of light-colored igneous rocks.

A. HEAD OF PORCUPINE CREEK.

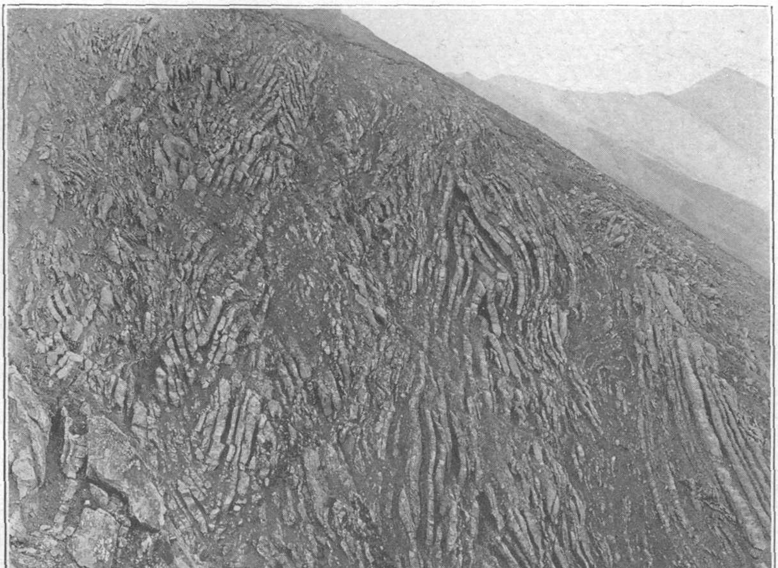
Showing cirque and "rock glacier." (See Pl. XIV, *B*.)



B. FOLDED THIN-BEDDED TRIASSIC LIMESTONE BETWEEN CLEAR AND SQUAW CREEKS.



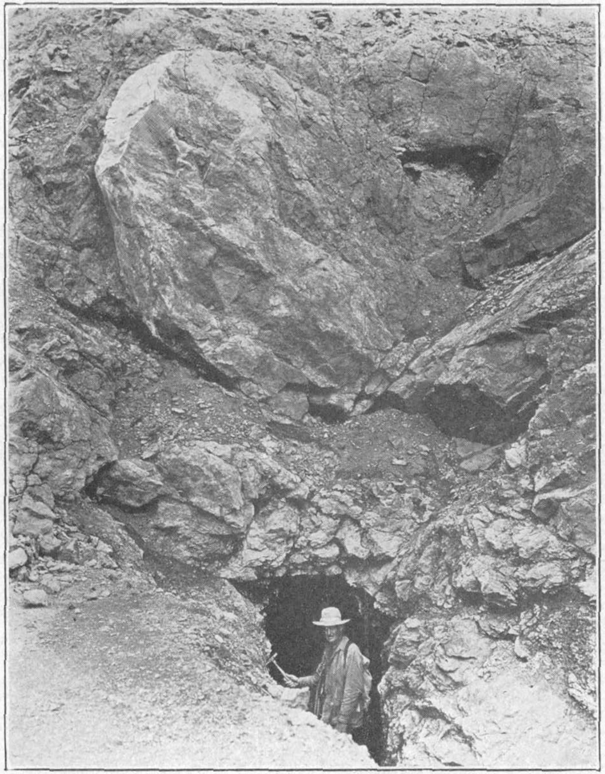
A. TRIASSIC ARGILLITE AND SHALE ON THE EAST BRANCH OF ROCK CREEK.



B. THIN-BEDDED TRIASSIC CALCAREOUS ARGILLITE AND SHALE NEAR FORKS OF ROCK CREEK.

The exposure is near a fault, and the beds are intensely folded.

A. THE COPPER "NUGGET" FROM WHICH NUGGET CREEK TAKES ITS NAME.



B. COPPER ORE ON THE BIG HORN GROUP.

The large disklike mass over the tunnel is a mixture of bornite and chalcocite.

to the southwest. The first belt lies in normal position to the Chitistone limestone but is limited on the southwest by one of the major faults of the district. The second belt in included between two great faults.

Figure 4 shows the relations between the Chitistone limestone and overlying Triassic beds on Lime and Rock creeks and indicates a type of structure seen at several places in the district in which the long flanks of the folds are merely tilted and the bends are closely compressed. Plate XV, *A*, shows the southwest slope of the ridge between the two streams, on which there is a thickness of several hundred feet of thin-bedded limestone and shale. Plate XV, *B*, looking in the opposite direction, is a view on Rock Creek at the foot of the slope shown in the first picture. Although the scale of the two views is greatly different, they show clearly the different effects of compression on the limbs and bends of the folds. The shale resting on the Chitistone limestone at the heads of Copper and Pass creeks is the northeast limb of a synclinal trough made up of Chitistone limestone, Kuskulana shale, and Kotsina conglomerate that extends from Kotsina River to the east fork of Strelna Creek. A narrow band of shale resting on the limestone north of Elliott Creek is apparently part of the southwest limb of this same syncline. These relations are shown on the section (Pl. III, in pocket).

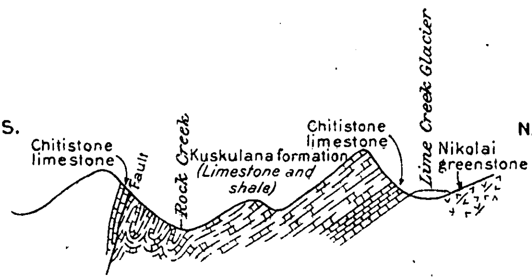


FIGURE 4.—Section of the Upper Triassic sediments of Rock Creek. This figure shows a type of folding found at several places in the district.

The broad major features of structure that have been described are complicated by a large number of minor faults and are obscured in places by the presence of the Kotsina conglomerate, which was deposited unconformably on the underlying rocks.

INTRUSIVE ROCKS.

All the intrusive rocks in the Kuskulana formation within this district are in the form either of dikes or of sills. They consist of quartz diorite porphyry and quartz latite and are widely distributed but are particularly numerous in certain localities. One large sill of quartz diorite porphyry in the valley of Rock Creek is more than 3 miles long and has a thickness ranging from 15 to 20 feet. A similar but smaller dike intrudes the thin-bedded limestone and shale on Lime Creek, and another intrudes these beds in the mountain south of Clear Creek. The most conspicuous examples of the quartz latite are the dikes and sills such as appear in the mountains between Kotsina River and Elliott Creek, at the heads of Magpie and Five Sheep creeks, and east of Pass Creek. Many small tabular bodies from 2 to 20 feet in thickness were forced between or through the shale beds in these localities. The sills are more numerous than the dikes and because of their position in the bedding planes of the shale have a parallelism that is readily seen on the map. These intrusives invaded the shale after the shale had been much folded, and it is probable that the dikes and sills, although they may appear to be folded in places where they follow the curved surfaces of the shale beds, have not undergone much deformation of that kind, but they have been faulted in many places.

Locally the dikes and sills brought about a silicification of the limestone and shale which they invaded. This silicification is especially noticeable near the intrusives in the Kuskulana formation west of Sheep Mountain and on the west branch of Rock Creek.

The strong contrast between the light-colored porphyry intrusives and their dark host makes the dikes and sills conspicuous, and they are therefore more easily seen than similar intrusives in the Chitistone limestone and in the members of the Nikolai greenstone. There is no doubt, however, that intrusives are more common in the Kuskulana shale than in the other rocks of the district.

AGE AND CORRELATION.

The shale, argillite, and limestone that have been described above are of Upper Triassic age. They contain numerous fossils at certain horizons, particularly in the thin-bedded limestone and limestone-shale beds, which give conclusive evidence on this point.

A list of fossils from the thin-bedded limestone, interstratified thin limestone and shale beds, and shale of the Kuskulana formation is given below. The list is divided into two groups in order to indicate the paleontologic evidence on which Martin's division of the formation is made. This division had previously been made for the Nizina district by Rohn,[28] by Schrader and Spencer,[29] and by Moffit and Capps[30] but was based on lithologic and not on paleontologic grounds, and no attempt was made to make the fossil *Pseudomonotis subcircularis* diagnostic of the McCarthy shale. A fauna essentially like that of the Chitistone limestone is shown in the first group. *Pseudomonotis subcircularis* practically constitutes the second group. This form is exceedingly common in some of the alternating limestone and shale beds, being so abundant that the shale can not be split without disclosing fragments of the shells.

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

[29] Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, Alaska, p. 46, U. S. Geol. Survey special publication, 1901.

[30] Moffit, F. H., and Capps, S. R., Geology and mineral resources of the Nizina district, Alaska: U. S. Geol. Survey Bull. 448, p. 11, 1911.

Fossils collected from the Kuskulana formation in the Kotsina-Kuskulana district.

[Identified by T. W. Stanton.]

	1	2	2202	2206	4804	8147	8149	8150	8151	8153	8154	8156	8157	8158	8160	8162	8169	8928	8929	8930	8933	8941	8942	8943	8944	8945
Upper part of Kuskulana formation, in beds equivalent to McCarthy shale:																										
Pseudomonotis subcircularis (Gabb)			×	×	×										×	×										×
Pseudomonotis	×	×																								
Pecten															×											
Undetermined pelecypods												×														
Lower part of Kuskulana formation, in beds equivalent to Nizina limestone:																										
Orbiculoidea?																					×					
Halobia cf. H. superba Mojsisovics						×	×				×											×			×	
Halobia sp								×	×	×	×			×			×			×			×			
Halobia?													×													
Myophoria?											×															
Pecten (2 or 3 species)																					×					
Tropites																			×							
Juvavites?																							×	×		
Ceratites?											×		×	×												
Arcestes?																			×				×	×		
Undetermined ammonites														×				×								

	9920	9921	9922	9923	9924	9925	9926	9927	9928	9930	9931	9932	9934	9935	9936	9937	9938	9939	9940	9941	9943	9944	9945	9947	9948
Upper part of Kuskulana formation, in beds equivalent to McCarthy shale:																									
Undetermined coral	×																								
Pseudomonotis subcircularis (Gabb)	×						×				×				×	×	×	×	×			×		×	
Lima (Plagiostoma) sp. undetermined																×									
Halorites sp. aff. H. americanus Hyatt																						×			
Juvavites?																						×			
Lower part of Kuskulana formation, in beds equivalent to Nizina limestone:																									
Halobia cf. H. superba Mojsisovics		×		×	×	×		×	×	×		×											×		
Halobia sp									×				×	×						×					×
Halobia?																					×				
Gastropod undescribed														×											
Tropites cf. T. subbullatus Haner														×											
Juvavites (Anatomites) sp. aff. J. subintermittens H. and S.														×											
Juvavites sp.?														×											
Arcestes sp. undet.						×																			
Arcestes sp. probably undescribed														×											
Arcestes? sp			×																						
Discropotites cf. D. sandlingensis Haner														×											
Arpadites sp.??														×											
Undetermined ammonites																					×				

1. West side of Kuskulana River. Oscar Rohn, 1899.
2. West side of Kuskulana River, a short distance north of No. 1. Oscar Rohn, 1899.
2202. Creek on north side of Kuskulana River. A. C. Spencer, 1900.
2206. Head of Rock Creek, from black slaty limestone in thin-bedded limestone and slate series. F. C. Scharader, 1900.
4804. Magpie Creek, 1 mile above junction with Elliott Creek. F. H. Moffit, 1907.
8147. 300 feet above canyon of Strelna Creek. F. H. Moffit, 1912.
8149. North Fork of Strelna Creek, shale area 600 feet south of first large branch on east. F. H. Moffit, 1912.
8150. North fork of Strelna Creek, 2,000 feet north of first large branch on east. F. H. Moffit, 1912.
8151. First branch of north fork of Strelna Creek near its mouth, float. F. H. Moffit, 1912.
8153. Clear Creek. Theodore Chapin, 1912.
8154. Ridge south of Clear Creek. Theodore Chapin, 1912.
8156. First creek south of Clear Creek, from black calcareous shale. Theodore Chapin, 1912.
8157. First creek south of Clear Creek, from gray limestone. Theodore Chapin, 1912.
8158. Clear Creek, from thin-bedded limestone and shale. Theodore Chapin, 1912.
8160. Divide between Clear Creek and Rock Creek, ridge east of Dixie Pass, elevation 6,100 feet. Theodore Chapin, 1912.
8162. Divide between Clear Creek and Rock Creek, trail on ridge south of 6,270-foot peak, elevation 6,100 feet. Theodore Chapin, 1912.
8169. Divide between Nugget and Roaring creeks, from thin-bedded shale. Theodore Chapin, 1912.
8928. North Fork of Strelna Creek, elevation 3,000 feet. F. H. Moffit, 1914.
8929. 4,700 feet N. 57° E. from forks of north fork of Strelna Creek, elevation 4,000 feet. F. H. Moffit, 1914.
8930. Left branch of north fork of Strelna Creek, mouth of gulch about 1,400 feet above forks. F. H. Moffit, 1914.
8933. Creek entering Kotsina River from north at junction of Kotsina and Kluvesna rivers, elevation 3,400 feet. F. H. Moffit, 1914.
8941. About 100 feet above trail at same locality as 8943, from limestone above 8943 and 8942. G. C. Martin, 1914.
8942. About 10 feet above trail at same locality as 8943, from limestone a few feet above 8943. G. C. Martin, 1914.
8943. Outcrop by side of trail at gulch on north side of Kotsina River about 1½ miles below Kluvesna bridge. G. C. Martin, 1914.
8944. Float from same locality as 8943. G. C. Martin, 1914.
8945. Rock Creek, elevation 3,475 feet. G. C. Martin, 1914.
9920, 9921, 9922. North fork of Strelna Creek.
9923, 9924, 9925, 9926, 9927. East branch of east fork of Strelna Creek.
9928. North branch of east fork of Strelna Creek.
9930. Ridge between Dixie Pass branch of Strelna Creek and Clear Creek.
9931. Ridge 200 feet north of 9930.
9932. South brow of round-topped hill on ridge between east fork of Strelna Creek and small creek between Squaw and Clear creeks.
9933. Ridge between east fork of Strelna Creek and Clear Creek.
9934. West branch of Rock Creek.
9935. Top of ridge between forks of Rock Creek.
9936. Gulch leading from west branch of Rock Creek to saddle between Rock Creek and east fork of Copper Creek.
9937. Highest point of ridge between east fork of Copper Creek, Pass Creek, and Rock Creek.
9938, 9939. West branch of Rock Creek.
9940. 3,000 feet northwest of Dixie Pass.
9941. East branch of Rock Creek near Dixie Creek.
9943. Gulch tributary to east fork of Rock Creek from north side.
9944. Same gulch as 9943, but only 200 feet from Rock Creek.
9945. Dixie Pass branch of Strelna Creek.
9947, 9948. Squaw Creek.

Whether the presence of *Pseudomonotis subcircularis* in the Kuskulana formation indicates a new fauna such as might be expected in rocks laid down on a land surface that had undergone erosion for a long period and had then been submerged, rather than a fauna made possible by a changing environment, not connected with a period of land erosion, in sediments continuously deposited is by no means established. This fossil is exceedingly abundant at certain horizons, in both the hard limestone and argillite beds and in the shale partings between the hard beds. It was found repeatedly within a few feet stratigraphically of exactly similar beds containing the typical fauna of the Chitistone and Nizina limestones and within 500 feet of the Chitistone limestone. On Strelna Creek at the point where the trail to the west fork of Rock Creek leaves the creek and starts up toward the pass there is a good exposure of impure yellowish-weathering platy limestone with paper-thin shale partings, striking N. 20° W. and dipping 20° W. These beds contain *Pseudomonotis subcircularis* abundantly in the shale partings and less abundantly in the limestone. They overlie black limestone in beds from 8 to 10 inches thick with little or no shale between, which strike N. 10° W. and dip 25° W. The black beds are 50 feet stratigraphically below the yellow-weathering limestone and crop out in the creek bank 150 feet east of them. They contain *Halobia.* Outcrops are practically continuous for 700 or 800 feet to the east and show that the limestone becomes less impure as the beds are followed downward, that the shale disappears entirely, and that the dip of the strata increases gradually for most of that distance. At a point 600 feet from the *Pseudomonotis*-bearing beds the limestone strikes N. 30° W. and dips 30° W. A noticeable feature of the purer limestone beds is that they pinch and swell and the bedding planes show a wavy surface. The most distant outcrops show variable strikes and dips. *Arcestes* was found about 400 feet stratigraphically below the *Pseudomonotis*-bearing beds. These details are given to show the orderly succession of deposits within the Kuskulana formation; they might be duplicated from other localities. They do not preclude the possibility of an erosion interval within the formation, but they do not suggest it and at least they indicate that no structural unconformity is present.

The fossils as interpreted by Mr. Stanton do not furnish grounds for separating the thin-bedded limestone at the base of the Kuskulana formation from the Chitistone limestone, for the fauna of the two are essentially the same. This separation must be made on lithologic grounds.

In the table facing page 34 the Kuskulana formation is correlated with other formations of southern and southwestern Alaska. It will be seen that the Kuskulana formation is represented as equivalent to the Nizina limestone (upper part of the Chitistone limestone as represented by Moffit and Capps[31]) and the McCarthy formation.

The McCarthy formation includes a considerable thickness of black chert, exposed on Nikolai Creek and on Folin Creek but not known in the Kotsina-Kuskulana district. Its most common fossil is *Pseudomonotis subcircularis.*

The type locality of the McCarthy formation is on McCarthy Creek,[32] where it has a thickness of probably not less than 2,500 feet.[33] Below the McCarthy formation are about 300 feet of alter-

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[31] Moffit, F. H., and Capps, S. R., Geology and mineral resources of the Nizina district, Alaska: U. S. Geol. Survey Bull. 448, p. 21, 1911.

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

[33] Moffit, F. H., and Capps, S. R., op. cit., p. 29.

nating limestone and shale beds that were regarded by Moffit and Capps as forming a transition zone between the Chitistone limestone and the McCarthy formation. In the light of the work done in the Kotsina-Kuskulana district in 1912 and 1914 it appears probable that these transition beds, together with about 1,200 feet of thin-bedded yellowish-weathering limestone containing only a small proportion of shale, included by Moffit and Capps in the Chitistone limestone, are the equivalent of the upper thin-bedded limestone and limestone-shale beds of the western area in this district. These are the beds that are now included in the Nizina limestone and that give rise to the difficulties in dividing the Upper Triassic rocks of Chitina Valley into formations consistent within themselves.

The Chitistone limestone and overlying Triassic limestone and shale are present along the south flanks of the Wrangell Mountains as far east as their type localities in Nizina Valley. Probably they extend still farther toward the head of Chitina Valley, for the Nikolai greenstone and Chitistone limestone are exposed near the head of Canyon Creek east of Young and Chititu creeks.

On the northeast side of the Wrangell Mountains, the east end of the Alaska Range, called the Nutzotin Mountains, is made up largely of Mesozoic rocks that include Upper Triassic beds.[34] Their extent is not known, but a mass of limestone in Cooper Pass yielded fossils on the evidence of which the limestone was correlated with the Chitistone limestone. The fossils include *Pseudomonotis subcircularis*, which suggests a correlation with the thin-bedded limestone or the thin-bedded limestone and shale of the Chitina Valley. For the same reason, at least a part of the Triassic limestone in the headwater regions of Gulkana and Susitna rivers[35] would be correlated with the same beds.

UPPER JURASSIC ROCKS.

CHARACTER AND DISTRIBUTION.

The rocks of the Kotsina-Kuskulana district that are regarded as belonging to the Upper Jurassic epoch lie unconformably on the Triassic and older rocks and include conglomerate, grit, sandstone, shale, and limestone. Among these rock types conglomerate is by far the most abundant. Its greatest development is seen in a narrow belt extending northwestward from the head of Strelna Creek to the north side of Kotsina River. Rohn[36] saw its outcrops in 1899 and called it the Kotsina conglomerate. Outcrops of the finer-structured

[34] Moffit, F. H., and Knopf, Adolph, Mineral resources of the Nabesna-White River district, Alaska: U. S. Geol. Survey Bull. 417, pp. 27–32, 1910.

[35] Moffit, F. H., Headwater regions of Gulkana and Susitna rivers, Alaska: U. S. Geol. Survey Bull. 498, p. 33, 1912.

[36] Rohn, Oscar, op. cit., p. 431, pl. 52.

fragmental rocks and the limestone are confined to a few relatively small areas scattered over the district.

The belt of rock just mentioned is made up of massive black conglomerate, almost without lines of bedding, yet containing a little black shale. It is composed largely of waterworn pebbles and cobbles, most of which are plainly of local origin and are derived from the underlying formations. Pebbles of greenstone, limestone, the light-colored granodioritic intrusives, and quartz are most common. It was noticed repeatedly that in the vicinity of areas of the Chitistone limestone the limestone pebbles in the conglomerate increase greatly in number and form a large proportion of the rock. The same is doubtless true of other constituents of the conglomerate, but these are not so readily seen.

The pebbles are inclosed in a shaly or arkosic matrix which disintegrates rather easily and breaks down rapidly under the influence of weathering. In consequence the outcrops are rough, and the talus slopes consist largely of pebbles freed from their matrix. The conglomerate mountains are rugged, with precipitous cliffs and a ragged sky line (Pls. V, *B*, and XII, *B*, pp. 6, 30). Their dark color and rough surface give them a forbidding aspect, and in fact many of the ridges are practically impassable.

A few thin beds of black shale are interstratified with the conglomerate but form an insignificant part of the whole. The sandstone and limestone members of the Jurassic are of much greater extent. The massive conglomerate (Kotsina) occurs in a curving belt that extends from Strelna Creek to and beyond Kotsina River. On the mountain between Clear Creek, tributary to Kotsina River, and Kluvesna River it has a much finer structure than in its southeasterly extension, changing first to a grit made up of tiny flattened pebbles of fairly uniform size and then to a soft yellowish-brown fossiliferous sandstone. About 50 feet of massive light-gray limestone with a slightly sugary texture and surface peppered over with tiny black specks rests on the brown sandstone and is overlain in turn by a small thickness of gray limy sandstone. Both the limestone and sandstone are fossiliferous.

Three small areas of Jurassic sandstone and conglomerate are faulted into or rest on the Kuskulana formation in the mountains west of Clear Creek in Kuskulana Valley. Approximately 800 feet of interbedded sandstone and conglomerate are exposed in the largest of these areas, near the head of Sheep Creek. The Upper Jurassic sediments rest unconformably on Triassic shales and are faulted against them on the west. At the base is 200 feet of conglomerate, and above is sandstone with intercalated conglomerate beds.

Farther south, on the west side of Sheep Creek, the Jurassic rocks comprise a basal sandstone bed overlain by limestone and are folded and faulted into a position between massive Chitistone limestone on the west and thin-bedded Triassic limestone on the east. The relations are shown in figure 5.

Another small mass of conglomerate and sandstone caps one point of the mountain between Sheep and Squaw creeks. It dips gently westward and rests unconformably on eastward-dipping limestone and shale beds.

Small masses of yellowish-brown sandstone are associated with the Triassic rocks on the ridge between Nugget and Roaring creeks.

A small collection of Jurassic or Cretaceous fossils was made near the top of the mountain between Rock and Lime creeks. The fossils were collected from loose rock within 100 feet of the top of a sharp ridge and when found were supposed to belong in the Triassic thin-bedded limestone. They probably came from a small residual area of Jurassic or Cretaceous beds remaining on the ridge which was not discovered during the field work.

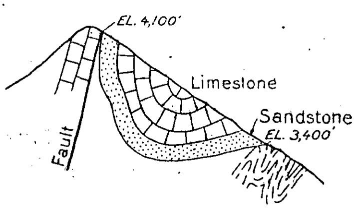

FIGURE 5.—Diagram showing structural relations between Triassic and Jurassic sedimentary beds on Sheep Creek.

Two small masses of Jurassic limestone are exposed on Trail Creek, east of Kuskulana River. The limestone north of Trail Creek is from 75 to 100 feet thick. It lies horizontally and is overlain by limy sandstone containing fossils. This area and the small one near by may have been connected formerly with the much larger area of sandstone, conglomerate, and shale that is exposed in the upper valley of Trail Creek and is continuous with the Jurassic sedimentary beds between Berg and MacDougall creeks. In the latter locality the Jurassic beds rest on quartz latite porphyry. The lowest bed is a grit or fine conglomerate containing pebbles of chert, fine-grained basalt, and light-colored granitic rock like the underlying porphyry. Above it are alternating beds of limestone, sandy in places, and yellowish-brown sandstone. Still higher on the mountain are black sandy shale, gray shale, and brown sandstone beds considerably folded in their upper part.

STRUCTURE AND THICKNESS.

The Upper Jurassic rocks lie unconformably on the upturned edges of the older formations. In some places they rest on the basal tuffs and lava flows; in others on the Chitistone limestone and the Kuskulana limestones and shales. A good exposure of the contact of the Jurassic rocks and the Kuskulana formation (Pl. XII, *B*,

p. 30) was seen at the head of a small creek flowing into Kotsina River from the north about half a mile below the mouth of Kluvesna River. The Jurassic sediments rest on contorted argillite and shale. A vertical fault striking N. 35° W. cuts the two formations but seemingly has caused little displacement. West of the fault the base of the Jurassic sediments is a bed of coarse conglomerate, about 50 feet thick, containing boulders as much as 12 inches in diameter. Many of these boulders are amygdaloidal greenstones. Above the conglomerate is several hundred feet of fossiliferous brown sandstone. The contact of conglomerate and sandstone is undisturbed by faulting.

East of the fault likewise the sandstone is separated from the Triassic shales by conglomerate. The conglomerate is variable in thickness, however, and is much thinner than the conglomerate west of the fault. At this locality it is not over 5 feet in its thicker sections and in places is reduced to a foot or less. Apparently the conglomerate filled depressions in an old land surface and is thickest where the depressions were deepest. The relations of the shale, conglomerate, and sandstone are shown in figure 6.

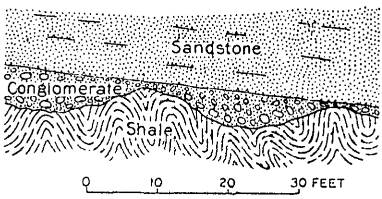

FIGURE 6.—Sketch of the contact of Jurassic conglomerate and Triassic shale on a small stream joining Kotsina River near the mouth of the Kluvesna.

About 500 feet of Jurassic beds, consisting chiefly of fine conglomerate, grit, and sandstone, is exposed at this locality. The contact of the conglomerate and sandstone was examined carefully for some evidence of unconformity but without success. The change from conglomerate to sandstone is rather abrupt, yet the bedding is conformable, and scattered pebbles like those of the conglomerate are seen in the lower part of the sandstone.

Less than half a mile to the east the Jurassic sandstone, much reduced in thickness, and the Jurassic limestone rest on Chitistone (Upper Triassic) limestone. The original relations are not entirely clear. Some faulting has taken place, yet it does not appear probable that such a thickness of conglomerate and grit as lies near by on the west ever intervened between the Triassic and Jurassic limestones at this place. It seems necessary to suppose either that the thick massive conglomerate and the sandstone were not widespread formations constituting the base of the Jurassic sediments generally, or, if they were, that most of them were removed before the limestone was deposited. This second interpretation introduces an unconformity, or possibly two unconformities, inasmuch as the thinning out of the sandstone must also be explained, for which other evidence was not found. The first interpretation is believed to be the correct one.

The Jurassic beds are considerably folded, though much less so than the older formations. Folding is not easily recognized in the massive conglomerate and is doubtless less pronounced there than in the thinner, less resistant members. The beds north of Kotsina River have been disturbed little by folding, but those southeast of Kuskulana River between Berg and MacDougall creeks are much deformed and have a strike more nearly east than appears in any of the formations northwest of the river. The dip is to the south. At least 500 feet of beds is exposed here.

The Jurassic sedimentary rocks show their maximum thickness in the conglomerate area north of Elliott Creek. There is no means of knowing the depth of the deposits in the synclinal trough between Elliott Creek and the head of Copper Creek, but if the base of the conglomerate were a plane the thickness of conglomerate involved would be at least 1,500 feet. In all probability it is much more, so that 2,000 to 2,500 feet is a reasonable estimate. This, moreover, if correct may be a maximum thickness, for the Jurassic sandstone, shale, and limestone west of Kluvesna River and southeast of Kuskulana River are possibly to be regarded for the most part as deposits contemporaneous with the conglomerate and not as overlying beds.

The great thickness of coarse, massive conglomerate north of Elliott Creek suggests the possibility that this part of the Jurassic sediments was accumulated on land or close to the shore along the front of a mountain range where the streams were discharging a great amount of transported material. The conglomerate shows almost no bedding, contains only a few thin shale beds, and shows a uniform structure through a great part of its thickness. The grit, sandstone, and limestone, on the other hand, are undoubtedly of marine origin and may be the seaward equivalents of the conglomerate.

INTRUSIVE ROCKS.

The intrusives in the Jurassic sediments are all, so far as is known, of the quartz diorite porphyry type. They have the form of dikes cutting the conglomerate or intruded along the contact of the conglomerate and the older, underlying rocks. Dikes were not seen in the Jurassic sandstone and limestone. They are most numerous in the conglomerate north of the lower end of Elliott Creek and north of Kotsina River.

AGE AND CORRELATION.

The rocks that have been described above are regarded as in large part if not entirely of Upper Jurassic age. Fossils that would determine definitely the age of the Kotsina conglomerate and its few interstratified shale beds were not found, although Mr. Alfred Wandke, during the course of an examination of the copper deposits of Elliott Creek in 1916, collected abundant shells of *Pseudomonotis subcircularis* from a large boulder embedded in the conglomerate on the east side of Alice Peak. Fossils are plentiful in the finer-structured detrital members and in the limestone. All the collections made by the writers were referred to T. W. Stanton for identification, and the list of fossils is given in the following table:

Upper Jurassic fossils in Kotsina-Kuskulana district.

	2196	2198	2210	2211	8155	8168	8924	8926	8934	8935	8936	8937	8939	8940
Serpula											×			
Rhynchonella							×							
Terebratula							×							
Terebratula?							×							
Spiriferina?							×							
Nucula?											×			
Pinna? (young)											×	×		
Inoceramus sp. 1 [a]	×	×												
Inoceramus (large form)							×							
Inoceramus				×	×			×	×	×	×	×	×	×
Pecten							×	×			×	×		
Astarte?											×			
Lytoceras?										×				
Perisphinctes?											×	×		
Belemnites (large species)			×											
Belemnites					×	×					×			×

[a] This is the species listed by Schrader and Spencer as *I. eximius* but is not the same as *I. eximius* Eichwald.

2196. Impure fossiliferous limestone 2¾ miles above the mouth of Clear Creek, "from a large bouldery slab." F. C. Schrader, 1900.
2198. Same locality as 2210. F. C. Schrader, 1900.
2210. Mountain 1½ to 2 miles north-northeast of camp 13 C, on Clear Creek, from sandstone. F. C. Schrader, 1900.
2211. North fork of Kuskulana River. Schrader and Spencer, 1900.
8155. First creek south of Clear Creek, from buff sandstone. Theodore Chapin, 1912.
8168. Divide between Nugget and Roaring creeks. Theodore Chapin, 1912.
8924. Mountain north of mouth of Kluvesna River, about 2,000 feet S. 12° W. of 6,005-foot peak, near base of grits. J. B. Mertie, jr., 1914.
8926. Southwest side of Trail Creek along trail, elevation 3,300 feet, from limestone. F. H. Moffit, 1915.
8934. Mountain north of mouth of Kluvesna River, float from same locality as 8935. F. H. Moffit, 1914.
8935. Mountain north of mouth of Kluvesna River, about 1¾ miles N. 47° W. from Ammann's cabin on Kluvesna River, from sandstone beneath a limestone bed. F. H. Moffit, 1914.
8936. Mountain north of Kluvesna River, about 9,950 feet N. 40½° W. from Ammann's cabin on Kluvesna River, elevation 5,800 feet, from sandstone beneath a limestone bed. F. H. Moffit, 1914.
8937. Mountain north of mouth of Kluvesna River, same locality as 8936, but from base of the sandstone overlying the limestone bed. F. H. Moffit, 1914.
8939. Ridge between Slatka and Trail creeks, 1½ miles S. 39° E. from mouth of Slatka Creek, elevation 4,800 feet. F. H. Moffit, 1915.
8940. Boulders in Limestone Creek near confluence with Clear Creek. G. C. Martin, 1914.

An analysis of Mr. Stanton's report on the 14 fossil localities listed in the table shows that the fossils from one locality are regarded as Jurassic, those from five localities as probably Jurassic, those from one as probably Upper Jurassic, and those from six as either Jurassic or Cretaceous. Possibly both Jurassic and Cretaceous time is represented in these collections, but in the absence of more definite evidence for the presence of Cretaceous rocks it was decided to consider all the rocks Jurassic. The collection from an unlisted locality on Trail Creek, a short distance southeast of the boundary of the area mapped, contains *Aucella*, the typical fossil of Rohn's Kennicott formation, and is definitely referred to the Upper Jurassic. The soft impure sandstone or arkose containing this fossil appears to be part of the eastward extension of the belt of conglomerate, sandstone, and shale represented on the map about 1½ miles southwest of Trail Creek and considered to be equivalent to the conglomerate and sandstone beds between Clear and Squaw creeks.

Upper Jurassic sediments are extensively developed in Chitina Valley. The name Kennicott has been applied to them by earlier workers but is not employed here, for reasons that will be given. This name was used by Rohn [37] to designate a succession of "light-colored arkoses, shales, and impure limestone typically exposed around the head of Kennicott Glacier" and was also applied by him [38] to the "light-gray, rather coarse grained arkose" beds that he found in the valley of Folin Creek and in the mountains north of Kennicott Pass in the Nizina district. Rohn examined the Jurassic sediments near Kuskulana Pass but lost the fossils collected from them and was unable to correlate the rocks of the two localities. The use of the name was later extended by Schrader and Spencer [39] to include all the Jurassic rocks that they found in Chitina Valley. Still later Moffit and Capps [40] included in the Kennicott formation a great thickness of black shale that is widely developed in the Nizina district and was mapped by Schrader and Spencer as part of the Triassic shales and limestones. This assignment by Moffit and Capps was made on the evidence of fossils which, as was ascertained later, were not sufficiently diagnostic to permit an accurate age determination. The recent work of Moffit [41] advances the black shale still higher in the time scale and places it in the Upper Cretaceous. The term Kennicott has thus been used to designate both Jurassic and Cretaceous sediments only recently differentiated and still imperfectly known. For this reason it seems desirable to restrict it to Rohn's original definition and to include in the formation only beds containing the characteristic fossils of his localities.

Jurassic rocks correlated with those of the Kotsina-Kuskulana district are exposed on Nikolai Creek and in the upper part of Copper Creek valley in the Nizina district. They consist of grit, sandstone, and a small amount of conglomerate and in the Copper Creek locality are overlain by Upper Cretaceous shale. Their total thickness is unknown, for they have not been differentiated from the overlying

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[37] Rohn, Oscar, A reconnaissance of the Chitina River and the Skolai Mountains, Alaska: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, p. 431, 1900.

[38] Idem, p. 424.

[39] Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, Alaska, p. 48, U. S. Geol. Survey special publication, 1901.

[40] Moffit, F. H., and Capps, S. R., Geology and mineral resources of the Nizina district, Alaska: U. S. Geol. Survey Bull. 448, pp. 31–43, 1911.

[41] Martin, G. C., U. S. Geol. Survey Bull. — (in preparation).

Cretaceous shale, but the basal conglomerate and grit range from 25 to 125 feet. This much at least is regarded as of Jurassic age. With it should probably be included the yellow-weathering sandstone and shale of Nikolai Creek, which reach a thickness of not less than 500 feet.

The known Jurassic rocks of the upper Chitina Valley[42] include only soft brownish or pinkish sandstone and gray sandstone, both of which contain concretions, the largest 2 feet or more in diameter, some of them abundantly fossiliferous. The largest area is east of Barnard Glacier, where about 500 feet of beds is exposed. Doubtless the several small areas remaining are parts of a formerly widespread and continuous formation.

Rocks of Upper Jurassic age are known in Matanuska Valley, in the Cook Inlet region, and on the Alaska Peninsula. These correlations are given in the table facing page 34.

CENOZOIC SEDIMENTS.

QUATERNARY SYSTEM.

GENERAL CHARACTER OF DEPOSITS.

Morainal deposits, stream gravels, including bench gravels and the present flood-plain gravels, talus piles, and deposits of unsorted rock waste such as result from weathering and accumulation, with little or no transportation by streams, are the principal Quaternary deposits of the district. These unconsolidated deposits merge into one another, so that in most places it is impossible to draw a sharply dividing line between them. Talus piles and other rock waste, everywhere present on the hill slopes, move downward under the influence of gravity, rain, and frost, till they cover the margins of gravel benches and morainal débris and then are overgrown with vegetation, so that even the approximate position of a boundary is often in doubt. The débris left by the glaciers is always influenced in some degree by the streams of water from the melting ice, and on the other hand the morainal deposits after they are deposited are frequently attacked and redeposited by the streams. In the same way the bench gravels are undermined, transported for greater or less distances, and finally laid down once more to await the beginning of a similar cycle at some future time.

The gravels on the wide flood plains of Kluvesna, Kotsina, and Kuskulana rivers and of some of the larger creeks have been distinguished on the map (Pl. III, in pocket) from bench gravels of exactly the same origin. It should be remembered, however, that all the streams have more or less gravel of this kind in their chan-

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[42] Moffit, F. H., The upper Chitina Valley, Alaska: U. S. Geol. Survey Bull. 675, pp. 27–28, 1918.

nels. On the other hand, no attempt has been made to distinguish from one another the morainal deposits, bench gravels, and talus piles. The residual material resulting from rock decay is present everywhere except where the slopes are too steep for it to stay or where it has been removed by wind or water. It is not distinguished on the map.

A rather unusual form for rock waste unsorted by stream currents to take is shown in Plate XVI, *B* (p. 38). The small, platy fragments from the quartz latite intrusive between Slatka and Trail creeks cover the hill slope and have been thrown into a wavelike form, resembling giant ripple marks.

MORAINAL DEPOSITS.

Nearly all the typical morainal deposits of the district are along its southwestern border in Chitina Valley. Great quantities of débris were dumped there by the huge Chitina Glacier as it retreated up the valley, so that a view from the mountains on the north shows a wide expanse of valley floor dotted with lakes separated by ridges of gravel and boulders. Not all the depressions are occupied by ponds or lakes, however, for hundreds of the potholes have walls sufficiently permeable to allow the water to drain away.

The most typical glacial deposits within the district are the moraines about the edges of Kuskulana Glacier and at the lower ends of the small glaciers between the upper part of Kotsina River and the Kuskulana. With these deposits should possibly be included also the so-called rock glaciers[43] (Pls. XIV, *A*, *B*, and XVII, *A*, p. 38), of which there are several good examples in the area.

The morainal deposits about Kuskulana Glacier include a few heaps of débris near the terminus of the ice (Pl. XVI, *A*, p. 38), which have escaped destruction by the glacial waters, and long lines of marginal moraine on each side of the glacier. Such marginal deposits appear as long ridges, like railroad embankments, from 10 to 30 feet high, in the depression between the ice and the mountain slopes. They do not form one continuous ridge, although at first sight they seem to do so. Many such marginal moraines when followed up the valley for a sufficient distance are found to merge into the mountain slope and new moraines begin between them and the ice. The long embankments thus overlap one another slightly. Prospectors take advantage of the lateral moraines in traveling along the glacier and have established very good trails on some of them.

Lateral moraines like those seen along Kuskulana Glacier are not present along the small glaciers between Kuskulana and Kotsina

[43] Capps, S. R., U. S. Geol. Survey Bull. 448, p. 52, 1911.

rivers. Most of the débris carried down by the small glaciers is dumped at the lower end of the ice stream to form irregular heaps of terminal moraine. In places the terminal moraines merge into the "rock glaciers" (Pl. XVII, *A*, p. 38). On the other hand, the best examples of "rock glaciers" within the area do not head in glaciers at present or are associated only with small snow and ice masses in the cirques in which they originate. The most striking of the "rock glaciers" is on the south side of Kotsina River between Rock and Roaring creeks. It is about 1½ miles long and 600 or 700 feet wide, except at the lower end, where it spreads out to a width of 2,500 feet along the river. Its surface is marked with the characteristic flow lines, longitudinal in places but concentric and more or less parallel to the margins in the broadened terminal lobe. No ice is visible in the débris, and very little is seen at the heads of its branches. The material composing it is pushed out onto the flood plain of Kotsina River, which flows along the margin but has been unable to remove the débris and maintain its own position. A few straggling spruce trees are scattered over the lower end.

Another "rock glacier" (Pl. XIV, *A*, p. 38) about 1 mile long lies a little to the west of the one just described, and a third occupies the upper valley of Amy Creek. The map (Pl. III, in pocket) shows other examples, but most of them are much more evidently connected with glaciation than the large one on Kotsina River and do not show in any such perfection the surface flow lines. Surface markings are present, but most of them have the appearance of successive marginal or terminal moraines rather than of lines due to movement of the whole mass.

Glacial débris that has undergone more or less sorting by water is intimately associated with bench gravels along the valley sides and is not distinguished from them on the map.

STREAM GRAVELS.

Under stream gravels are included the present flood-plain deposits of the rivers and larger creeks and elevated bench gravels and other unconsolidated water-laid gravels that were deposited by streams during recent stages in the geologic history of the region. Both the flood-plain gravels and the bench gravels contain a large amount of material contributed to them directly by the glaciers and not resulting from the more common processes of weathering and stream erosion.

The flood-plain gravels of Kuskulana, Kotsina, and Kluvesna rivers range in width from a few hundred feet to one-third of a mile. They are subject to flooding at times of high water and are bare of vegetation, for the streams migrate from side to side over them, shifting the gravels and attacking the banks on each side.

In flood times enormous quantities of gravel are moved either down the valley or across it and are spread out over the flood plain or deposited along the margins of the bars. The flood plains of the small streams are narrow, in few places exceeding 100 or 200 feet and in many places being little wider than the stream channel.

The valley floors adjacent to the flood plains of the large streams and bordering many of the small streams consist largely of gravel deposits that are covered with vegetation but that formerly were flood plains like those over which the streams now flow. Some of these bench deposits are only a few feet above the streams; others stand many feet above them. Some of these lower benches are succeeded by other more elevated benches, some of which are older flood plains; others, especially those along the valley slopes, are deposits laid down by streams along the margin of the glacier. The latter deposits are scarcely distinguishable in places from morainal material that was laid down at the same time. Some of them merge into or are overlapped by talus débris from the mountain sides.

The elevated gravels, except where they form conspicuous topographic features or are exposed in stream cuttings, are commonly difficult to distinguish from other loose surface deposits on the mountain slopes, especially where they are overgrown with vegetation.

Deposits of gravel along the sides of Chitina Valley run up to altitudes between 2,500 and 3,000 feet above the sea, but on Kotsina and Kuskulana rivers they reach 4,000 feet locally, and on some of the small streams they extend even higher.

All the unconsolidated surficial deposits of the district were laid down either during or since the retreat of the glaciers. No evidence of older, preglacial gravels has been discovered in the district.

IGNEOUS ROCKS.

By J. B. Mertie, Jr.

OUTLINE.

Igneous rocks supply an important part of the geologic record in the Kotsina-Kuskulana district. A number of different types have been recognized and are here described, but it is believed that the descriptions are not fully representative of the Chitina Valley. Additional detailed work in adjoining areas will doubtless reveal varieties other than those here described and will probably disclose evidence of other periods of volcanism, which will throw additional light upon the volcanic history of the district.

The igneous rocks of the district comprise both intrusive and extrusive varieties and range from rocks older than Upper Triassic to rocks of post-Jurassic age. The lack of geologic sediments of

Tertiary age renders it impossible to differentiate any volcanic epochs subsequent to the deposition of the Upper Jurassic sediments. The region, however, has been and still is a center of volcanic disturbance, and there is every reason to believe that volcanic action has been a potent factor in the history of the region at different periods in Tertiary and Quaternary time. At present Mount Wrangell is intermittently active, though none of the recent lavas are found in the Kotsina-Kuskulana district.

Bedded extrusive lavas constitute a part of the basal formation (Strelna) in this district and all of the Nikolai greenstone. The lithology, age, and correlation of the bedded lavas have been set forth in the description of the geologic formations of the district. The petrographic description is here given in more detail.

The intrusive rocks are separated, so far as the field and microscopic data permit, into major divisions on the basis of relative age. Chemical, mineralogic, and textural variations constitute the basis for further subdivision. The geologic study of the district in 1914 justifies the recognition of three major periods of volcanic activity. These are designated pre-Upper Triassic, post-Triassic, and post-Jurassic. The post-Jurassic division may embrace several volcanic epochs.

EXTRUSIVE ROCKS.

LAVAS OF THE STRELNA FORMATION.

Bedded lavas and tuffs constitute a large part of the Strelna formation, perhaps as much as 85 or 90 per cent of the entire sequence. The sedimentary rocks of this formation are described on pages 21–28. A petrographic description of the igneous rocks of the formation is given below.

The lavas included in the Strelna formation are altered basalts and diabases, similar to those which constitute the overlying Nikolai greenstone. They are composed essentially of a plagioclase (usually labradorite), augite, and iron oxides. In general, the plagioclase and pyroxene have suffered extensive alteration to chloritic and serpentinous products, giving rise to the so-called greenstones. In the description of the Nikolai greenstone this type of rock is treated more fully. Except that the lavas of the Strelna formation are finer grained and contained perhaps slightly more original glass, all that will be said of the lavas of the Nikolai greenstone applies equally well to these flows.

The fragmental rocks of igneous origin are essentially of two kinds—subaerial and water-laid. The subaerial deposits consist of beds of volcanic detritus, which was ejected from volcanic vents and came to its present position without the aid of surface waters. The water-laid deposits are composed of volcanic material that has been reworked to a greater or less extent by surface waters. It is not always possible to distinguish between these two varieties of pyroclastic rock, for volcanic detritus that has been deposited in quiet water and not reworked does not look materially different from other detritus that accumulated on the land. This is especially true in the Kotsina-Kuskulana district, where the pyroclastic rocks have suffered a considerable amount of subsequent alteration, which has tended to obscure or destroy the diagnostic data. Therefore the genesis of many of these tuffs must remain undetermined. In this district only those pyroclastic rocks that afford in their texture positive evidence of water action may be classed with certainty as water-laid. The very fact, however, that water was present near the centers of eruption, as shown by the subangular to rounded character of some of the detritus and by the presence of interbedded sediments, is good reason for the belief that some of the volcanic material probably fell directly into quiet water or else was transported only a short distance and deposited therein without any considerable amount of reworking. On the other hand, the major part of the tuffaceous material in the upper portion of the Strelna group gives no evidence of water action and is associated with the lava flows rather than with sedimentary beds. The general stratigraphy of the beds laid down during this period, too, is indicative of dominantly terrestrial rather than marine conditions. Therefore, it is likely that more of the tuffs were subaerial than water-laid.

In addition to the tuffs should be mentioned the flow breccias, which were noted at a few localities. These rocks represent flow and fracture in partly solidified and therefore viscous portions of the lava streams. Except for the curving flow lines that characterize the matrix of such rocks, they do not look materially different from the tuffs, from which indeed they are in places difficult to distinguish.

There is considerable diversity in the appearance of the tuffs, due to variations in the size and color of the component fragments. The individual pieces range from microscopic dimensions up to an inch or more in diameter, and the larger pieces are perhaps the more abundant. Red, brown, green, and grayish tuffs are common; and where the fragments that constitute the rock are large enough to be visible in the hand specimens and differ in color, rather striking mottled effects are seen. The finest grained of these tuffs have a dense lithoidal appearance, and many of them break with a conchoidal fracture. Such rocks, if gray or greenish gray, resemble so closely some of the silicified sediments that a microscopic examination is necessary to discover their true character, and in the very finest grained specimens even this is inadequate. In addition to the variations above noted, the almost conglomeratic character of the water-worked varieties and the flow lines that are common in the flow breccias make diversity of appearance a marked feature of this pyroclastic series.

Under the microscope the fragments that constitute the tuffs are seen to be for the most part basic volcanic material in so advanced a stage of alteration that exact determination of its original petrographic character is difficult. As a rule the material is basaltic and similar to that of the associated flows. Laths of plagioclase and equant grains of pyroxene, usually augite, both much chloritized, together with more or less chloritized glass and grains of iron oxides, constitute the basaltic material. Lighter-colored fragments of andesitic nature have also been noted. These consisted of hornblende, a little pyroxene, altered plagioclase, and a little iron oxide and apatite in a microcryptocrystalline groundmass. Flows similar to this have not yet been observed in the tuffaceous series. Fragments of andesine, labradorite, quartz, pyroxene, and epidote are also found and in all probability have been derived from older intrusive rocks. The matrix of these tuffs is usually either doubtfully crystalline or exhibits only aggregate polarization; and this condition, coupled with the alteration to secondary products, renders the original character undeterminable.

Another class of rocks, commonly referred to in the field as cherts, merit some mention. These are dense light-gray to greenish-gray siliceous rocks, which break with a conchoidal fracture and which have been observed interbedded with the lavas. They are so fine grained that the microscope is of little assistance in determining their origin, though microscopic work suggests an igneous origin for a few of them. Silicification has been so prominent in the limestone and other rocks of this complex that it would not be unusual if many of these rocks originated in that way. The finest of the tuffaceous material, being in a minute state of division, would naturally be easily acted upon by permeating solutions. In the absence of any evidence pointing to the deposition of original cherts the writer is inclined to believe that many of these siliceous beds are of secondary nature and represent partial or total silicification of fine tuffaceous material.

In several localities, notably in the lower part of Iron Creek and on the spur to the east of Amy Gulch, the Strelna formation and the intrusive rocks that cut it have suffered a considerable amount of dynamic metamorphism. In the lower part of Iron Creek, at an altitude of 2,650 feet, basic diorite is exposed along the trail. In going upstream every gradation may be seen from this rock into a sheared and entirely recrystallized schistose rock. Farther upstream the massive tuffaceous beds are entirely unaffected. Again, on the east side of Amy Gulch tuffaceous beds were encountered which were rendered schistose along a zone of faulting. In other localities this has been noted to a lesser degree. Such examples are typical of the character of the dynamic metamorphism which has affected the Strelna formation. It is local and confined entirely to zones of shearing and intense deformation. It should be noted, however, that such zones are more common in the Strelna formation than in the Nikolai formation. This is susceptible of two interpretations. One would utilize this fact as evidence that the Strelna formation had suffered more deformation than the overlying Nikolai greenstone; the other would explain it as due to the superior rigidity of the Nikolai. The writer is inclined to favor the latter interpretation, but the former might constitute good supplementary evidence in case a time break is ever demonstrated to exist between the Strelna and the Nikolai.

Intrusive pyroxene diorite and gabbro have been noted at many localities in intimate association with the rocks of the Strelna formation. These intrusives occur in dikes, sills, and larger and more irregular shaped bodies. The Nikolai greenstone on Nugget Creek and on Clear Creek, in the Kuskulana Valley, is also apparently intruded by large bodies of this type. The petrographic description of these rocks is given in a section devoted to the intrusive rocks of the district (p. 67).

So far as observed, granular basic intrusives similar to these do not invade any of the rocks above the Nikolai greenstone. This fact constitutes a basis for the belief that these intrusives represent a period earlier than the deposition of the Upper Triassic and later sediments. Moreover, the gabbros and related rocks do not appear to penetrate any considerable distance into the Nikolai greenstone. While this fact might be interpreted as due to the rigidity of the Nikolai lavas and the consequent resistance which they offered to igneous intrusion, a more likely interpretation is that these intrusions ended or became less violent toward the end of the period represented by the outflow of Nikolai lavas. It is certainly logical to believe that the termination of such a period of profound igneous extrusion should be accompanied by a corresponding diminution or cessation of intrusive action.

NIKOLAI GREENSTONE.

LITHOLOGY.

The term Nikolai greenstone is used to designate a thick series of basaltic lava flows overlying the Strelna formation and occupying a considerable proportion of the area under consideration. This name was used first by Rohn,[44] who applied it to the "greenstone" that "contains the Nikolai copper vein" on McCarthy Creek west of Nizina River. The geologic map published by Rohn [45] represents the

[44] Rohn, Oscar, A reconnaissance of the Chitina River and Skolai Mountains, Alaska: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, p. 425, 1900.

[45] Idem, pl. 13, p. 404.

Nikolai greenstone of the Nizina district and the bedded volcanic rocks at the head of Kotsina River by the same symbol. These bedded volcanic rocks are now known to be older than the typical Nikolai greenstone and are here separated as the Strelna formation, the name Nikolai being applied to the coarser-grained and generally amygdaloidal lavas overlying them. This distinction is based on lithologic differences and is strengthened by the possibility of an unconformity at the base of the Nikolai.

The Nikolai greenstone consists of thick flows of basalt (Pl. XVI, *A*, p. 38) without intercalated sedimentary beds. In general these flows are coarser grained than the basalts of the Strelna formation. They are more commonly amygdaloidal, and they show the bedded character much less distinctly. Individual flows are distinguished with difficulty. The basalt flows are prevailingly dark green but locally appear reddish or reddish brown as a result of alteration. Their thickness is probably not less than 6,500 feet.

The Nikolai greenstone is made up of strong, resistant rocks, but the beds have been thrown into broad folds, whose limbs have steep dips in places. The pressure that produced intricate folding in the softer rocks found relief in the greenstone through faulting and the production of joints, along which movement of smaller amount has taken place. Everywhere the greenstone is found to be crossed by fracture planes that divide the rock into blocks of different shapes and sizes, many of them showing slickensided surfaces. Such rocks are readily broken down through freezing and thawing, so that the bases of nearly all the greenstone cliffs are hidden by talus piles made up of greenstone blocks. In this way also a characteristic topography of rugged summits and smooth lower slopes is produced.

The Nikolai greenstone is exposed in a broad belt extending northwestward across the northeastern half of the district and in isolated areas in the southwestern half, particularly on Copper, Elliott, and Strelna creeks and near Kuskulana River. Its structure is well shown in the northeastern area, where in many places it dips southwest under the Chitistone limestone. This is true also of Copper Creek, but on Elliott Creek the dip is reversed and the greenstone goes down under the limestone on the north. Apparently all the areas of Mesozoic rocks are underlain by the Nikolai greenstone, which thus forms a broken and much disturbed trough extending through the central part of the area mapped. Some anomalies are found, however, for in a few places, notably on Nugget Creek, Triassic limestone rests on rocks referred to the Strelna formation. In the absence of confirming evidence to the contrary, this condition is regarded as the result of faulting rather than as due to depositional unconformity.

THICKNESS.

It is not possible to make a reliable estimate of the thickness of the Nikolai greenstone in the Elliott or Strelna Creek basins, because at the former locality the base is not exposed, and at the latter the structure is so complex that it is impracticable to make the necessary calculations. In the valley of Kotsina River, however, just above its confluence with the Kluvesna, the geologic structure is thought to be sufficiently simple to insure a fairly accurate estimate of the thickness of the Nikolai. From data in hand the thickness there is calculated to be about 6,500 feet.

AGE AND CORRELATION.

Direct evidence by which the age of the Nikolai greenstone can be determined has not been found. The greenstone of the Kotsina-Kuskulana district overlies rocks from which lower Carboniferous fossils have been obtained and is overlain by a massive limestone of Upper Triassic age. It is therefore younger than the known Carboniferous and older than the known Triassic rocks of the district.

Recent work in another district makes it possible to restrict these age limits somewhat. During the field season of 1922 Mr. Moffit collected fossils from sandy beds and a lime conglomerate underlying the Nikolai greenstone on Chitistone River about 50 miles east of Strelna. These sediments are interstratified with tuff beds, lava flows, chert, and argillite, forming a succession of bedded rocks which are prevailingly volcanic and underlie the massive flows of the Nikolai greenstone with structural conformity. The fossils were submitted to George H. Girty for identification and are referred by him to the lower part of the Permian. It is evident, therefore, that the Nikolai lavas were extruded at a time intermediate between the deposition of the early Permian sediments and that of the Upper Triassic sediments.

Neither the Kotsina-Kuskulana district nor the neighboring districts of Chitina Valley have yet yielded unmistakable evidence showing the structural relation of the Nikolai greenstone to the overlying and underlying formations. In most places where these relations have been studied there appears to be a complete parallelism of structure, yet some other lines of evidence suggest the presence of an unconformity either at the top or bottom or at both top and bottom of the greenstone. In some localities the base of the Nikolai greenstone shows the "pillow structure" that is regarded by some geologists as evidence that the lavas were poured out under water. Only a few such localities are known, and even if the "pillow structure" is proof of extrusion under water, those parts of the greenstone that have this structure do not necessarily indicate the presence of more than local bodies of water. Probably much if not most of the Nikolai greenstone was poured over a land surface and must have been subjected to weathering for at least a brief interval before the flows were submerged and deposition of the Chitistone limestone began. A thin bed of shale between the greenstone and limestone in the Nizina district[46] may possibly represent a thin soil that covered the lava flows. It is believed, however, that the time during which the flows may have been subjected to the action of atmospheric agents must have been short, for no evidence of the greenstone surface having been eroded has ever been found, and the structural accordance of the greenstone and limestone would indicate that the lavas had not been deformed before the limestone was deposited.

Capps[47] has presented evidence to support his belief that the Nikolai greenstone on upper Nizina River overlies the Permian limestone conformably.

This is in accordance with the later observations made by Mr. Moffit in the near-by locality on Chitistone River in 1922 and suggests that whether or not a structural unconformity exists between the Strelna formation and the Nikolai greenstone it is highly probable that an erosion interval immediately preceded the extrusion of Nikolai lavas in the Kotsina-Kuskulana district, for Pennsylvanian and early Permian sediments are not known there.

Without more definite knowledge of the age of the Nikolai greenstone, it is difficult to make correlations that are likely to prove correct with similar rocks in other districts. One possible correlation, however, will be pointed out.

The Nikolai greenstone of Chitina Valley extends eastward from the Kotsina-Kuskulana district to the head of Chitina River. A belt of rocks similar in many respects to the Nikolai greenstone extends along the south side of the Alaska Range from Gulkana River to Susitna River. This belt of rocks[48] is about 15 miles wide and consists mainly of diabase lava flows that are locally amygdaloidal. They are associated with argillites, tuffs, and tuffaceous conglomerate and are cut by dikes of intrusive rock. These lava flows appear from the meager evidence available to overlie limestone containing a few imperfect fossils that are regarded as of lower Carboniferous age and to be overlain by Triassic limestone and shale. Their stratigraphic position appears, therefore, to be like that of the Nikolai greenstone. The rocks themselves, in their association

[46] Moffit, F. H., and Capps, S. R., Geology and mineral resources of the Nizina district, Alaska: U. S. Geol. Survey Bull. 448, p. 21, 1911.

[47] Capps, S. R., The Chisana-White River district, Alaska: U. S. Geol. Survey Bull. 630, p. 47, 1916.

[48] Moffit, F. H., Headwater regions of Gulkana and Susitna rivers, Alaska: U. S. Geol. Survey Bull. 498, p. 29, 1912.

of tuffs and argillites with lava flows, resemble the combined Strelna formation and Nikolai greenstone rather than the greenstone alone. The correlation of the rocks of these two regions is regarded as probable but is by no means established.

PETROGRAPHIC CHARACTER.

There is considerable variety in the appearance of the greenstone in the hand specimens, depending on the granularity, fabric, and recognizable minerals of the groundmass, the size and number of phenocrysts, the color of the rocks, the amount of chemical alteration that has taken place, the character and size of the amygdaloidal fillings, and the deformation that the rocks have undergone. All gradations may be seen from dense aphanitic specimens to rocks of medium grain. In the medium-grained rocks the diabasic texture can usually be distinguished and the minerals of the groundmass, particularly the feldspar, can often be recognized. Feldspar and pyroxene occur as phenocrysts, but commonly only the feldspar is visible in the hand specimens. Phenocrysts of plagioclase as large as 6 millimeters have been observed, but the average size is from 2 to 3 millimeters. As a rule the rocks are not richly porphyritic, and in some of them no phenocrysts are to be seen. In general the greenstone is dark in color, and the development of secondary minerals has added a decided greenish hue. Not uncommonly, however, the rocks appear reddish or reddish brown as the result of certain forms of alteration. The amygdaloidal fillings consist of calcite, chloritic and serpentinous material, quartz, epidote, and zeolites, and the resulting white, green, or grayish spots which these fillings cause lend further diversity to the general appearance of the rocks. Locally the greenstone has suffered considerable deformation, due largely to shearing, and all traces of the original structure have disappeared, leaving a dark-greenish nondescript rock which may be entirely recrystallized.

At a few localities the lava of the Nikolai greenstone has been found to be ellipsoidal at the base. This is exceptional, however, and so far as known ellipsoidal lavas do not occur elsewhere in the formation.

Among the greenstone specimens that have been examined only a very few contain any appreciable amount of glass. Much of the greenstone, however, originally contained glass in considerable amounts, but in the course of subsequent alteration the glassy material was changed for the most part to serpentinous or chloritic products. Were the volcanic glass the only rock material that has been chloritized, it would not be difficult to estimate the original glass content, for the anhedral areas would then represent original glass. But both pyroxene and feldspar have often been altered to secondary products that are identical in appearance with the chloritic and serpentinous material that has resulted from the alteration of glass. This, then, renders an accurate estimate of the original crystallinity of the rock impossible. To judge by the fairly coarse grain and general habit of numerous specimens, it appears that much of the greenstone was originally holocrystalline. On the other hand, there are fine-grained specimens which show with little doubt that a considerable portion of the original rock was glassy, for a part at least of the original glass is itself still preserved. It is very doubtful if there are any specimens in which the proportion of glass amounts to one-third of the total rock, and usually where glass is recognized with certainty it does not exceed 10 or 15 per cent. Hence, a fair statement is that most of the greenstone was originally holocrystalline.

Most of the greenstone proper is porphyritic, but different specimens vary in the character and amount of phenocrysts which they carry. Where the rock is porphyritic at all feldspar is an important phenocryst, and very commonly feldspar forms the only member of the first generation. Pyroxene occurs also as phenocrysts, but not so commonly, and is usually developed in smaller individuals. In many specimens, however, no phenocrysts are present and the rock is rather even grained.

The porphyritic greenstone may be described as perpatic, as the phenocrysts do not usually form any considerable proportion of the rock. The groundmass varies in fabric, but the diabasic or ophitic fabric is of frequent occurrence. In fine-grained varieties the pyroxene is interstitially distributed in fine grains between the feldspar, thus producing the intersertal fabric; and where glass enters as a prominent factor into the mode, the hypocrystalline-porphyritic fabric is produced. In one or two specimens the feldspar and augite appear to have crystallized more or less simultaneously, with the result that fine-grained hypidiomorphic-granular fabric has been developed. The diabasic or ophitic fabric, however, generally with but often without phenocrysts, is the type most commonly seen.

The primary minerals that have been observed, named in the order of their relative abundance, are augite, labradorite, iron ores, apatite, olivine, and orthorhombic pyroxene. A rough estimate, neglecting the presence of original glass, leads to the belief that the augite comprises about 50 per cent of the rock, feldspar 40 per cent, and iron oxides 10 per cent. Apatite is an accessory constituent; and olivine and orthorhombic pyroxene have been observed only in a few specimens.

The labradorite phenocrysts range from individuals 6 millimeters in size down to crystals no larger than 0.5 millimeter. The crystals are euhedral to subhedral, equant to prismatic, and are twinned polysynthetically by the albite law, rarely by the pericline law. Zonal growths are locally present, and not infrequently magmatic resorption has taken place. The feldspar always occurs in an altered condition, the alteration minerals being, in their order of relative abundance, sericite, kaolin, calcite, and chloritic products. In certain specimens epidote is developed.

Augite, although it occurs in phenocrysts as large as 1 millimeter, is usually much smaller than this, and porphyritic individuals as small as 0.3 millimeter occur, so that it must be considered a microporphyritic component. As a phenocryst augite is subhedral, equant, and colorless and often carries inclusions of labradorite.

At the time of the solidification of these lava flows augite was doubtless the most abundant rock-forming mineral, and in many specimens, in spite of subsequent chloritization, it still remains the dominant mineral of the greenstone. It occurs as a constituent of the groundmass in two general habits. In the coarser-grained greenstone augite is present as large anhedral grains, including laths of plagioclase feldspar, the two developing the typical ophitic fabric. Where the fabric is not coarse and particularly where some glass is developed, augite takes the form of subhedral equant grains, which, though interstitial to the feldspar, have yet on account of their smallness had an opportunity to develop crystal boundaries. Where interstitial, the maximum size of augite individuals is about 0.4 millimeter and the mean size is probably about 0.15 millimeter. The general habit of the augite is normal, being either colorless or a light yellowish green, nonpleochroic, and having the characteristic pyroxene cleavage. Twinning is rare. The secondary minerals commonly derived from the alteration of augite in the greenstone are chloritic and serpentinous products, and sometimes epidote is developed.

Labradorite, the second mineral in abundance, shows but little variation in habit. In the groundmass it is almost invariably developed as subhedral laths, twinned by the albite law. The maximum length of these lath-shaped crystals in the average greenstone is about 0.75 millimeter, and the mean length is about 0.4 millimeter. In some of the coarser-grained diabases feldspars having a maximum length of 1 or 2 millimeters have been observed, but these are exceptional. The feldspars of the groundmass, like the feldspar phenocrysts, alter into sericite, kaolin, calcite, and chloritic products. As with augite, the presence of epidote as an alteration product is an indication that a special phase of chemical alteration has taken place in the rock. This condition receives further consideration in the description of the copper ores (p. 97).

The iron ores, magnetite and ilmenite, take the form of subhedral to anhedral grains that rarely exceed 0.2 millimeter in diameter and are usually much smaller. They have likewise suffered alteration during the metamorphic processes involved and have given place to various secondary products, prominent among which are iron hydroxide and leucoxene.

Apatite may usually be found in small quantities in most of the greenstone in the form of tiny pale-greenish needles. It is not by any means plentiful or prominent.

Olivine is relatively scarce in the Nikolai greenstone but has been recognized in a number of slides. It alters very readily to serpentine and when observed is usually in an advanced state of alteration. Even when alteration is complete, however, the original character of the serpentine may be recognized by its pseudomorphism after the euhedral six-sided olivine crystals which preceded it; and a further distinguishing characteristic is the presence of hematitic antigorite or iddingsite along the irregular cracks which olivine commonly shows.

One of the specimens collected by Schrader and Spencer in 1900 contained faintly pleochroic crystals of orthorhombic pyroxene, associated with the augite. This is the only known occurrence of this variety of pyroxene in the district.

On account of the superior rigidity of the consolidated lava flows of the Nikolai formation, these have not suffered extensive deformation except locally along shear zones. Hence it may be stated that in general the metamorphism of the Nikolai greenstone has been chemical rather than dynamic.

Reference has already been made to a number of secondary minerals which result from the alteration of the component minerals of the greenstone. Thus sericite, kaolin, calcite, and chloritic products have been noted as the common alteration products of the feldspar, and in many rocks augite has been converted to chloritic and serpentinous products. Many of the original lava flows, however, had numerous gas cavities or vesicles which, by the agency of mineral-bearing solutions, were later filled to form amygdules. This development of amygdules from preceding vesicular cavities is as universal and as typical as the alteration of the feldspar and augite.

Many of the vesicles were filled by two or more minerals, which may be oriented concentrically with respect to the walls of the amygdules. Thus a yellow serpentinous material with low double refraction may line the cavity and grade inward into green pleochroic chlorite with noticeably higher double refraction. These two minerals may be arranged either radially with respect to the walls of the amygdule or in a succession of spherulites. In both arrangements, however, the orientation of the two minerals is usually the same, and they grade by insensible degrees into one another. In the center of the amygdule may occur either a colorless serpentine with very low birefraction, showing indigo interference colors, or calcite, or both. Other cavity fillings, though radially or spherulitically arranged, are homogeneous and consist of any one of a number of chloritic or serpentinous minerals. It is thought that the two outer linings which many of the amygdules show are due to chemical action between the walls of the cavities and the percolating solutions and where strongly developed indicate a certain amount of secondary enlargement of the vesicles, attendant on the process of mineral filling. It has been noticed, too, that the amygdules which are homogeneous or approximately so have in general much more regular shapes than those in which the different mineral linings were developed. Another evidence of secondary enlargement is the common occurrence of rock-forming minerals projecting into the amygdules. Thus, a feldspar lath may project straight into an amygdule, and it will then have the same double mineral lining as was formed on the rest of the cavity Moreover, various states in the chloritization of the projecting mineral may be observed, from the fresh, scarcely altered mineral to a completely chloritized and often detached crystal that is but faintly discernible in the surrounding chlorite. The calcite and the serpentinous or chloritic material which filled the centers of the cavities are considered to be due to the action of circulating ground waters.

Another though less common secondary process in the greenstone was the development of epidote and quartz as alteration products of the pyroxene and feldspar and as cavity fillings. As an alteration product of the rock-forming minerals epidote is more common than quartz, and pyroxene is more susceptible to epidotization than feldspar. The development of epidote and quartz in the greenstone, however, appears to be a chemical alteration of different type and apparently has been preceded by an earlier process in which chloritic material and calcite were the dominant secondary minerals. Where epidote and quartz occur as amygdular fillings, their habit, especially that of the epidote, is in euhedral crystals embedded in the chloritic material and the calcite. Additional light is thrown upon the development of epidote and quartz by the presence of veinlets of these two minerals which cut across the greenstone, spreading out locally and replacing the rock and its earlier secondary minerals. From these relations the conclusion is reached that the epidote-quartz mineralization was a later process than the development of at least some of the chloritic material and calcite. It is not inferred that the development of epidote and quartz was subsequent to all the chlorite-calcite mineralization, for evidence is available which points to still later rock alteration of the latter type. All that is postulated is an epidote-quartz mineralization which was superimposed on an earlier process of rock alteration and by which chloritic material, calcite, and unaltered primary rock minerals were replaced to a considerable extent. This development has been observed chiefly in association with and in the near vicinity of copper deposits, particularly though not exclusively in connection with the stringer lodes; and it is believed, therefore, that a genetic connection may exist between the copper mineralization and the development of quartz and epidote.

A third process of chemical alteration is the development of several zeolites and prehnite as vein and cavity fillings. Analcite and heulandite have been identified optically as vein fillings, and another zeolite which has not been correlated with any described species has also been noted. This zeolite is a tabular mineral, often radially arranged in fibers, with a prismatic cleavage. It has a mean index of refraction of about 1.52, is optically positive, and has a negative elongation. The extinction is parallel, and the interference colors are a little greater than those shown by quartz. In every way, except in its birefringence, this mineral corresponds to thompsonite, but in that one particular it is more closely related to natrolite. Moffit [49] has noted the presence of thompsonite as cavity fillings in some of the greenstones of the Nizina district. Prehnite has been seen in several slides and is probably connected genetically with the zeolites. So far as observed, the zeolites and their associate prehnite have not replaced the greenstone to any extent but are confined mainly to veinlets and amygdules.

INTRUSIVE ROCKS.

PRE-UPPER TRIASSIC IGNEOUS ROCKS.

BASIC DIORITE AND GABBRO.

Distribution.—Intrusive basic diorite and gabbro are not localized in any particular area at any definite horizon in the Strelna formation. Only in the upper part of Nugget Creek and at the head of Clear Creek, in the Kuskulana basin, do they intrude the Nikolai greenstone. Geographically they are found wherever the Strelna formation crops out, being therefore represented extensively in the Elliott Creek and Strelna Creek belt of this formation and in the eastern belt, particularly in the valleys of Roaring and Nugget creeks. Perhaps the largest single mass of the gabbro is at Iron Mountain, where much of the mountain and the ridge to the west appear to be made up of rock of this kind.

[49] Moffit, F. H., and Capps, S. R., Geology and mineral resources of the Nizina district, Alaska: U. S. Geol. Survey Bull. 448, p. 60, 1911.

Lithology.—The diorite and gabbro are confined to the Strelna formation and to the Nikolai greenstone, but most of the occurrences are in the Strelna. A striking feature of these intrusive rocks is the indefiniteness of their boundaries. On account of the alteration which they have undergone they do not differ materially in color from the inclosing greenstone, and in many places the contacts can be detected only by making a close examination of the outcrops and looking critically for a sharp change in the granularity of the rocks. Though it was impracticable to differentiate these intrusives on this account, enough was learned of their habit to justify the opinion that all the common forms of intrusive bodies are present, including dikes, sills, and laccoliths.

These granular intrusive rocks are of dark color, in places with a decided greenish hue. This is particularly true where the rocks have been greatly affected by percolating ground water. On the talus piles, such as occur on the sides of Iron Mountain, the débris is reddish brown. As a rule pyroxene and less commonly hornblende and feldspar are visible in the hand specimens, obviously in a decayed condition.

Petrographic character.—Under the microscope the rocks are observed commonly to have a granular nonporphyritic fabric. In a few places a poikilitic fabric is developed, in which numerous euhedral crystals of feldspar are inclosed in a single individual of pyroxene. A few of these intrusives are porphyritic, in particular some hornblende gabbro porphyry found at the head of Clear Creek, in the Kuskulana basin. The rock minerals consist essentially of pyroxene, less abundant hornblende, plagioclase, and oxides of iron. The accessory minerals are quartz, apatite, and orthoclase.

The plagioclase is commonly zonally grown and ranges in composition from oligoclase on the rims to labradorite in the centers. The outside rims, however, are thin and have little influence on the mean composition of the feldspar, which ranges from andesine to acidic labradorite. The twinning is according to the albite law. In many places the feldspar is badly altered throughout, but where the alteration is only partial the rims are less altered than the centers. Sericite and chloritic material are the usual alteration products. The pyroxene is the monoclinic variety augite and occurs in subhedral to anhedral individuals, many of which are less altered than the plagioclase. Twinning on the plane 100 is not uncommon. Pleochroic chlorite and related products are the secondary minerals that result from the alteration of the augite. Hornblende seldom takes the place of augite in the rock mode, the sole example known being in the hornblende gabbro above referred to, but in many places it occurs with augite as a subordinate constituent. Hornblende alters to biotite and chloritic products. The iron oxides are usually altered, being generally represented in the rock by hydroxides of iron.

Quartz is by no means uncommon but can not be classed as other than an accessory mineral. It occurs alike in gabbro and diorite as anhedral grains. Orthoclase is rare but may form a graphic intergrowth with quartz. Apatite is widespread in small amounts, usually as small anhedral grains.

The intrusive rocks have been designated diorites or gabbros, according to whether the feldspar was determined to be andesine or labradorite. Hence the rock types pyroxene diorite, gabbro, and hornblende gabbro have been recognized.

Age.—So far as observed, the basic diorite and gabbro are confined to the Strelna formation and the lower part of the Nikolai greenstone. The rocks of Upper Triassic age, which directly overlie the Nikolai greenstone, have not been intruded, nor has the upper part of the Nikolai greenstone. All that may be said of the age of these intrusives is that they are later than lower Carboniferous and earlier than Upper Triassic.

POST-TRIASSIC INTRUSIVE ROCKS.

GRANODIORITE AND QUARTZ LATITE.

Distribution.—The granodiorite at Granite Mountain and in the valley of Porcupine Creek and the latitic rock south of Kuskulana River are the largest outcrops of rocks of this type. Smaller areas were noted at the mouth of Pass Creek and on the southeast side of Kuskulana River, opposite the mouth of Clear Creek. Many sills and dikes of latitic material were seen at different places in the district, notably on the spur west of Sheep Mountain and southward into Elliott Creek.

Lithology.—Light-colored granodioritic rocks of variable granularity are found at a number of localities in the Kotsina-Kuskulana district. The coarser-grained rocks usually occur in larger bodies of the laccolithic type; the finer-grained varieties occur both in this way and in the form of sills and dikes. The phanerocrystalline or granodioritic types are as a rule nonporphyritic, but many of the finer-grained or latitic rocks carry phenocrysts of feldspar. As a rule these rocks, particularly the coarser-grained varieties, are not altered to any considerable extent.

The contacts between these intrusives and the neighboring rocks are well exposed and show that the intrusion was accompanied by great stresses, which crushed or otherwise deformed the invaded rocks to a high degree. This condition is expressed most forcibly by the ragged or uneven nature of the contacts at many places. Instead of a clean-cut contact between the intrusive and the country rock, there is usually a crushed zone of variable thickness, impregnated with igneous material. This is well shown in the lower part of Pass Creek, where the Chitistone limestone is intruded; in Porcupine Creek, where the Nikolai greenstone is invaded; and at Granite Mountain, where the stresses developed by the intrusion not only crushed the surrounding rocks but materially changed the strike and dip of the beds in the vicinity.

On the south side of Kuskulana River east of Slatka Creek a large body of quartz latite has intruded the Nikolai greenstone and the Chitistone limestone. This exposure shows in a striking way the irregularity of the contact line between the intrusive and the country rocks. A large block of Nikolai greenstone was almost engulfed in the quartz latite, and everywhere in the vicinity of the greenstone there is a well-developed flow structure in the lava. The irregularity of the contact suggests that perhaps other blocks of greenstone have been removed from the reentrants along the contact and have sunk or risen to other horizons.

Petrographic character.—The granodiorites are granular, usually nonporphyritic rocks, composed essentially of quartz, plagioclase, orthoclase, hornblende, and biotite. Magnetite, apatite, and titanite constitute the accessory minerals. The ratio of plagioclase to orthoclase is usually about 2 to 1. Plagioclase, hornblende, and biotite are present as subhedral crystals; the other essential minerals, quartz and orthoclase, have the form of anhedral grains. In the porphyritic rock, such as that along the southern border of the Granite Peak mass, plagioclase forms the prominent phenocrysts, and the groundmass is likely to be very fine grained. The plagioclase, which is commonly andesine, has been sericitized to some extent, but in general these rocks are not greatly altered.

The quartz latites, which are believed to be a finer-grained equivalent of the granodiorites, are granular rocks composed of quartz, plagioclase, orthoclase, biotite, and muscovite. In the specimens examined plagioclase and orthoclase are present in nearly equal amounts. The plagioclase forms subhedral laths in a cementing material composed largely of orthoclase. Only a little of the orthoclase has developed crystal boundaries. Though not badly altered, these rocks have undergone greater alteration than the coarse-grained varieties. The plagioclase, which is between oligoclase and andesine in composition, is somewhat sericitized, and this suggests that a certain proportion of the biotite and muscovite may be secondary. Specimens have been found showing the outlines of crystals thought to have been originally hornblende; but these were completely altered to iron hydroxides. The oxides of iron are likewise altered in this manner.

Contact metamorphism.—The intrusion of the granodioritic rocks appears to have been accompanied by contact metamorphism of the adjoining country rock at many localities. Such metamorphism was of two kinds—one resulting in the formation of high-temperature minerals, such as magnetite, garnet, pyroxene, and hornblende, and the other manifesting itself by silicification. At certain localities both kinds of contact metamorphism occurred. The first type was accompanied by the formation of low-grade copper deposits, consisting of pyrite and chalcopyrite. Such copper ores were formed at the head of Clear Creek and along a zone on the southeast side of Kuskulana River from McDougall Creek to a point a mile southwest of Berg Creek. The Copper Queen claim, in this second zone, affords the best illustration of both types of contact metamorphism. The tunnel on this claim has been driven for the first 100 feet in Upper Jurassic limestone, which has been completely silicified. Beyond this silicified limestone is porphyritic greenstone, which continues nearly to the face. This greenstone, consisting both of fine-grained and coarse-grained varieties, is intruded by numerous dikes and apophyses of porphyritic rock, of granodioritic character, which are the source of the contact metamorphism. Magnetite in irregular bodies and in disseminated form, accompanied by hornblende and pyroxene, is developed in this greenstone, and between the greenstone and the face of the tunnel a body of highly garnetized limestone has also been formed by the igneous metamorphism.

At the head of Clear Creek contact metamorphism similar to that at the Copper Queen claim is also developed, but not in such intense form, and the resultant high-temperature minerals are not so common. There has also been considerable silicification of the greenstone at this locality, accompanied by a certain amount of epidotization. It is of interest in this connection to note that quartz-epidote veinlets cut the Nikolai greenstone and Strelna formation at numerous places in the vicinity of the stringer lodes of copper, developing silicification and epidotization similar to that above described.

Silicification of the country rock adjoining the granodioritic intrusives is rather common. Thus, on the spur west of Sheep Mountain and extending soutward into the Elliott Creek basin an intricate system of latitic sills has silicified the Kuskulana formation to a considerable degree. Many of the thin beds of limestone between these sills appear to be completely silicified and resemble cherts most closely; and at one place in this vicinity the interbedded shale has been completely recrystallized to an aggregate of quartz and epidote.

At the head of the west fork of Rock Creek a narrow sill has silicified the adjoining thin-bedded limestone for a distance of several inches. On Mineral Creek, in the Kluvesna Valley, silification near the borders of the mass that composes Granite Mountain is common.

Age.—These rocks intrude the Strelna formation at Granite Mountain, the Nikolai greenstone in Porcupine Creek and the Chitistone limestone in the lower part of Pass Creek and are accordingly not older than the Upper Triassic. South of Kuskulana River, however, Upper Jurassic sediments rest unconformably upon the latitic rocks there exposed. It is concluded, therefore, that the latitic rocks are pre-Jurassic. If, as is now believed, the granodioritic and latitic rocks are equivalent in age, differing only in their granularity, these rocks are post-Triassic and pre-Upper Jurassic. At all events, the granodiorites are post-Triassic and the latites are pre-Upper Jurassic.

BASALT.

Little is known of basaltic rocks of post-Triassic age in this district. In only two localities are such rocks known to exist. Chapin in 1912 mapped a dike which he described as basalt porphyry, cutting the Chitistone limestone west of Clear Creek, in the Kuskulana Valley. During the season of 1919 the writers observed several basaltic dikes cutting the Chitistone limestone on the north side of Kluvesna River, north of The Peninsula. These dikes, however, were not of mappable size. These data, though meager, suffice to establish definitely that rocks of this type and age exist in the district.

POST-JURASSIC INTRUSIVE ROCKS.

QUARTZ DIORITE PORPHYRY.

Distribution.—Such of the post-Jurassic intrusive rocks as cut the Kotsina conglomerate are best developed in the vicinity of Sheep Mountain. There porphyritic dikes may be seen high up on the mountain side, cutting the black conglomerate. Quartz diorite porphyries which have been separated from the granodiorites on the basis of their chemical composition cut the Upper Triassic rocks west of Clear Creek, in the Kuskulana Valley, and at other localities. In the valley of Rock Creek a dike of quartz-feldspar rock that is too badly altered for exact determination is thought to belong to this class. This dike crops out for a distance of several miles, emerging in the Kotsina Valley.

Lithology.—Light-colored porphyritic rocks, not unlike the porphyritic phases of the granodiorites in general appearance but differing in chemical and mineral composition, are also found in this district. Such rocks have been noted cutting the Kotsina conglomerate, which is considered to be of Upper Jurassic age. In other surroundings the quartz diorite porphyries are difficult to distinguish from the granodiorites. The chief difference in the hand specimens is that the post-Jurassic intrusives are usually porphyritic, while the granodiorites are rarely so. These rocks are relatively scarce in the Kotsina-Kuskulana district and do not attain anything like the abundance which they show in the Nizina district, farther east. The quartz diorite porphyries have been found solely in the form of dikes and sills, some of which, however, have a considerable longitudinal persistence. No laccolithic bodies of this class are known in this district.

Petrographic character.—The rock consists of a fine light-grayish groundmass in which are set numerous phenocrysts of feldspar and quartz. The feldspar is plagioclase of the variety andesine. The groundmass is usually holocrystalline and consists of an intricate assemblage of plagioclase laths and quartz, with some hornblende and occasionally biotite. Orthoclase is rarely present, and it is in this respect that these rocks differ most markedly from the granodiorites. The plagioclase is commonly altered in greater or less degree to sericite and calcite, and almost invariably the fine-grained groundmass is altered to sericite, calcite, and chloritic products. Such iron oxdies as may have been originally present are changed to iron hydroxides. Apatite, quite unaltered, is a frequent accessory mineral.

Age.—On the basis of the relations above cited, the quartz diorite porphyries are believed to be of post-Jurassic age. However, it should be emphasized that only a portion of the rocks here classed together are definitely known to cut the Kotsina conglomerate. The age of the other quartz diorite porphyries is inferred from their similarity in chemical and mineral composition.

STRUCTURE.

By F. H. Moffit.

Pronounced folding and faulting are common to all the formations of the Kotsina-Kuskulana district. The Jurassic rocks show their effects least, but even in them the beds are locally much distorted by folding and nearly everywhere show displacement due to faulting. Among the older formations the Kuskulana shale and thin-bedded limestone and the rocks beneath the Nikolai lava flows are most deformed. The Kuskulana formation especially, except the limestone beds immediately overlying the Chitistone limestone, is folded in a most intricate way (Pls. XVII, *B*, and XVIII, *B*, p. 38). The soft shale and thin limestone beds were less able to withstand pressure than the massive Nikolai lava flows and the Chitistone limestone. Much of the movement and readjustment between the beds of the different formations took place in the soft shales, with the result that they were made thicker in some places and thinner in others and were everywhere deformed. The Chitistone limestone, although more resistant than the shale, was less so than the lavas and in a few places shows almost as much deformation as the shale (Pl. IX, *B*, p. 7). This folding, however, was accompanied by considerable faulting.

The best evidence of folding in the Carboniferous rocks is afforded by the limestone and chert beds. Individual beds of limestone or chert are more easily distinguished than beds of tuff or the fine-grained basalt flows, and although few of them can be followed for more than short distances and many are displaced or interrupted altogether by faults they nevertheless show that they are more intricately folded than the overlying Nikolai greenstone. This is doubtless due in large measure to the difference in the inherent ability of the rocks to withstand deformation.

Locally the rocks below the Nikolai greenstone have taken on a schistose structure that affects considerable areas along the lower mountain slopes bordering Chitina Valley. Schistosity is not seen in the younger rocks except that it has developed in narrow bands not over a few inches thick in fault and shear zones cutting the Nikolai basalts.

The sedimentary formations and associated lava flows northwest of Kuskulana River form a broad, shallow synclinorium in which Carboniferous tuffs and basalts lie on the northeast and southwest and the younger formations occupy the axial portion. The synclinorium is not simple but is made up of great folds forming minor synclines and anticlines and is further complicated by at least three lines of major faulting whose strikes are practically parallel to the axes of the folds. In general the trend of the great syncline is northwest, but the axes of the minor synclines and anticlines are divergent, opening out toward the northwest and ranging from about N. 30° W. on the northeast side of the great syncline to N. 60° W. on the southwest side. It thus appears that the great syncline is wider on Kotsina River than on the Kuskulana, but it is not fully evident that this is to be interpreted as due to a northwesterly pitch of the synclinal axis.

This major structural feature appears not to continue southeastward across Kuskulana River. In the vicinity of Slatka and Trail creeks the lava flows and sedimentary formations are intruded by a great mass of igneous rock that disturbs their normal relations and complicates their structure, while south of the mouth of Clear Creek the sedimentary formations trend almost at right angles to the strikes across the river. These transverse structural trends, although the dips are steep, may possibly indicate the end of a great synclinal or anticlinal fold. Not enough, however, is known of the formations about the head of Chokosna River to give much support to such an assumption. On the contrary, the work done on the heads of Slatka and Trail creeks seems to indicate a change in trend of the great structural features east of Kuskulana River.

Three major faults cut the formations of the Kotsina-Kuskulana district, producing great displacements and disturbing the normal succession of the beds. In addition, many smaller faults, some of them parallel with and some transverse to the trend of the beds, caused minor displacements and, in combination with folding, brought about a confusing association of irregularly shaped areas of different formations such as is found about the head of Strelna Creek.

The three major faults radiate from the mountain mass between the east fork of Strelna Creek and Clear Creek. One extends across Kotsina River to the top of the mountain between Kluvesna River and Clear Creek, which is tributary to the Kotsina. A second crosses the heads of Pass Creek and the forks of Copper Creek, apparently disappearing beneath the Kotsina conglomerate. The third crosses Strelna Creek and follows the south side of the Elliott Creek valley. In some places the three faults are plainly thrust faults with variable dips to the southwest—that is, the rocks on the southwest have been thrust up over the rocks on the northeast. In other places the dips are very high or are even reversed and inclined to the northeast. These statements for the most part are based on a study of the relation of the fault boundary to the topography rather than on observation of the fault plane itself, and it should be added that if the unconformity at the base of the black shale inferred by Martin is proved to exist, the anomalous relations of the shale and underlying formations at a number of localities may be explained as due to unconformity rather than to faulting. There is no doubt, however, that the contact of the Carboniferous and the Triassic rocks south of Elliott Creek and extending over into Strelna Creek valley is a fault contact. In the same way the long scarp of Chitistone limestone that extends from the head of Rock Creek down Pass Creek and across the Kotsina is regarded as due to faulting in which the limestone was thrust up over the shales on the northeast. The fault contact may be seen on Rock Creek and also north of Kotsina River, where it has a low southwesterly dip.

The intermediate fault—the one that extends across the heads of Copper, Pass, and Strelna creeks—offers some difficulty to an interpretation of simple overthrust alone. This fault appears to have been governed by a sharp fold in the Chitistone limestone. From the head of the west branch of Rock Creek to its last appearance west of Copper Creek this fault is readily explained as an overthrust fault with a variable southwesterly dip not exceeding 45° and in most places considerably lower than 45°. Between the west fork of Rock Creek and Strelna Creek, west of Dixie Pass, the limestone is faulted out except a few small masses along the fault line. Still farther east, on the easternmost fork of Strelna Creek, the limestone dips northeastward and is both overlain and underlain by Triassic shale, and dipping beneath all these rocks is the Kotsina conglomerate (Pl. XIII, *A*, p. 31).

The north-south fault of the Squaw Creek valley appears to be the continuation of this overthrust but may be a cross fault. It should be kept in mind that the present inclination of the fault planes is not necessarily the original inclination, for all the rocks have been more or less folded since part of the faulting took place. A study of the map will make it evident that the fault surfaces are not plane surfaces but warped surfaces, and doubtless they were so originally.

Another fault of almost as great extent as the three just described follows the valleys of Nugget Creek and Roaring Creek, striking parallel or nearly parallel with the main structural lines of the vicinity. Its exact position on Nugget Creek is not known, for an extensive body of gravel and talus covers the valley bottom. Probably it follows the east side of the valley, but it is complicated by a number of smaller faults. Its course across the divide between Nugget and Roaring creeks and down Roaring Creek can be determined with more accuracy. The dip of this fault is not known, but from observations of the fault plane it is believed to be high, so that the fault plane must be considerably warped. The displacement is such that the Carboniferous tuffs (Strelna formation) below the Nikolai greenstone on the west are brought into contact with the Chitistone limestone and the Nikolai greenstone on the east. This would indicate a displacement of beds equal to the thickness of the Nikolai lava flows, or about 6,500 feet.

It is known that thrust faults such as have been described cut the Chitistone limestone near the mouth of Kluvesna River, giving it a much greater thickness than is indicated by measurements in other localities, but no evidence was found to show that the southward extension of the limestone was thickened in this same way.

Cross faults and other minor faults are numerous throughout the area mapped. Many of them have doubtless escaped detection, and others are not shown on the map. A number are represented, however, and one of them may be mentioned. It is an east-west fault, crossing Squaw Creek, by which the Nikolai greenstone is brought into contact with shale of the Kuskulana formation. The displacement is thus not less than the thickness of the Chitistone limestone.

The most complicated faulting of the district, involving both strike and cross faults, is seen on the west branch of Strelna Creek.

GEOLOGIC HISTORY.

By F. H. Moffit.

The Carboniferous tuffs and fine-grained basalts bear evidence that the oldest rocks of the Kotsina-Kuskulana district were formed during a period of volcanic activity. A great thickness, measured in thousands of feet, of fragmental material thrown out during this period is mingled with flows of lava and shows few if any traces of normal sediments.

This purely volcanic material, however, is succeeded by material of the same kind intercalated with limestone, chert, and shale beds that indicate a temporary decrease in volcanic activity or at least a time when the processes of normal sedimentation prevailed over those of volcanism. From these sedimentary beds the evidence for the age of the deposits was obtained. The limestone contains fossils that show it to be of lower Carboniferous (Mississippian) age and thus contemporaneous with the Lisburne limestone of the Arctic coast.

Marine sedimentation did not continue to be predominant, however, and was followed, possibly in Permian or Triassic time, by a renewed volcanic activity and the piling up of many thousand feet of lava flows, part of which now constitute the Nikolai greenstone.

There is no evidence at hand from this district to indicate a period of uplift and erosion immediately preceding the extrusion of the Nikolai lavas. On the contrary, at the few places where the base of the Nikolai greenstone was observed the Nikolai lavas and underlying rocks seem to be structurally conformable. Such conformity, however, can not be regarded as proof that no time elapsed between the formation of the underlying beds and the outpouring of the lavas, and evidence has been given (p. 60) to indicate that the Nikolai basalt flows may have been poured out on the eroded surface of the Strelna formation.

There is also a lack of evidence regarding the relation between the topmost lavas of the Nikolai greenstone and the lower beds of the Chitistone limestone, so that it is not known at what time during the long interval between the early Permian and Upper Triassic epochs the Nikolai lavas were extruded. Some of the flows probably were poured out or solidified under water, but others evidently were not. Yet whichever condition prevailed when the last lava flows took place, it is certain that in Upper Triassic time the land was submerged and marine sedimentation was in progress. Some facts indicate that a time of uplift and erosion may have preceded the deposition of the Chitistone limestone, yet no definite proof of it is known. Among these facts are the presence in the older rocks of altered intrusives not found in the younger formations, the more advanced state of metamorphism of the older rocks, and the absence of any sediments containing fossils belonging to the time between the early Permian and Upper Triassic.

During Upper Triassic time the massive Chitistone limestone was deposited and was buried under many feet of thin limestone beds, which in turn were overlain by a greater thickness of black shale. All of this indicates a progressive change in the character of the material brought to the sea, the conditions under which it was deposited, and probably also the position of the shore line.

The Triassic sediments, together with the older formations, were next folded, were elevated above the sea, and, so far as is now known, underwent erosion till Upper Jurassic time, when they were again submerged and were buried under many feet of conglomerate, sandstone, and limestone. These rocks all suffered further deformation and were raised above the sea, but when the elevation took place is not known. No beds that can with certainty be assigned either to Cretaceous or to Tertiary time are present in the district. It would appear, therefore, that upper Mesozoic and Tertiary sediments were never deposited here or that if they were they have been entirely removed. It may not be possible to determine which alternative is more probable, especially as it is known that Cretaceous sediments were deposited a short distance to the east in Chitina Valley and that most of Alaska was a land mass in Tertiary time.

Deformation of the rocks in the Kotsina-Kuskulana district was accompanied or perhaps followed by the intrusion of igneous rocks in the form of dikes, sills, and large irregular-shaped masses. There appear to have been at least three periods when these intrusions took place, and there may have been more. Some of the altered dark-colored gabbroic and dioritic rocks of the Strelna formation are believed to be among the oldest of the intrusive rocks and to belong to a period of intrusion that preceded the deposition of the Chitistone limestone. They appear also to be older than the quartz latite porphyry on which the Upper Jurassic beds southeast of Kuskulana River lie and which is regarded as belonging to the second period of intrusion.

The youngest intrusives cut the Upper Jurassic beds and are therefore of Upper Jurassic or later age. Their intrusion may have accompanied the folding that deformed the Jurassic sediments.

The later geologic history of the district is concerned largely with the development of the present topography. The studies of geologists in many parts of Alaska lead to the belief that the present surface of the Territory is much like that which existed throughout most of the Tertiary period but that the relief at the end of the Eocene epoch was much less than now. This moderate relief resulted from long-continued erosion during which elevations of the land surface were reduced and depressions were filled. Wide areas of land and lake deposits were laid down, and much of the Alaskan coal was formed.

This long period of erosion and deposition was followed by a period of mountain building, when the present ranges were elevated and the main features of the present drainage were outlined. This is the condition that existed when glaciation began. The general appearance of the land probably was much the same then as now. Important changes in drainage have taken place, but the mountain chains and valleys are believed to have been altered only in their minor features. The larger features of the old topography were not destroyed by the invading ice but were so modified as to change a land surface resulting from normal subaerial erosion to one having the characteristic aspect of a glaciated mountain region.

Little is known of the beginnings of glaciation in the Wrangell Mountains, but the recent studies by Capps [50] in the White River district give some ground for the belief that the last great advance of the ice was contemporaneous with the Wisconsin stage of continental glaciation. How much earlier than this the first advance of the ice may have been it is impossible to say at present. Some idea of the extent and magnitude of the former glaciers may be had from the effects produced by them. It is probable that during the time of maximum glaciation only the highest peaks of the Wrangell Mountains were visible above the ice fields. The valley of Chitina River was occupied by a great ice mass that overrode the mountains south of the river and left definite evidence of its presence on peaks more than 5,000 feet above the sea. The broad basin of Copper River, also, on the west side of the Wrangell Mountains, was filled with ice or was bordered by piedmont glaciers that contributed an enormous quantity of material to the gravel and till deposits that fill it.

Glaciation left its most evident effects in the changed appearance it gave to the old topography. These effects are principally of two kinds, those produced by deposition and those produced by erosion. To these may be added changes brought about in the positions of stream courses.

The modifications of topography due to the removal of material are seen clearly in straightened and oversteepened valley walls, hanging valleys, and the smooth rounded contours of hills that were overridden by the ice.

From favorable points in Chitina Valley a view of the mountains on the north shows a succession of triangular faces or truncated spurs forming a steep, straight wall that sharply bounds the valley.

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[50] Capps, S. R., An estimate of the age of the last great glaciation in Alaska: Washington Acad. Sci. Jour., vol. 5, pp. 108–115, 1915; The Chisana-White River district, Alaska: U. S. Geol. Survey Bull. 630, pp. 61–80, 1916.

The present form of this wall is due largely to the great Chitina Glacier, which moved down the valley from the east and cut away the spurs projecting between the mountain streams. Similar results were produced by the glaciers of Kluvesna, Kotsina, and Kuskulana valleys.

These three valleys afford typical examples of the straight, oversteepened walls and U-shaped cross sections characteristic of strongly glaciated mountain valleys. Other examples are Elliott Creek valley, Rock Creek valley, and in fact practically all the larger valleys of the district.

Another topographic form, associated with glaciation and common in the district, is the cirque or steep-walled semicircular basin (Pl. XVII, *A*, p. 38) in which the valley glaciers now originate or from which such glaciers formerly came. The exact mode of their formation is in dispute, but they are to be connected with glaciation, and even where they are no longer the starting places for ice streams they are commonly occupied by bodies of snow and ice.

The glaciers that occupied valleys within the Kotsina-Kuskulana district did not leave much morainal material that was not subjected to sorting and redeposition by streams as soon as it was laid down by the melting ice. In places heaps of débris still remain, but in general the streams issuing from the ice removed the rock fragments as fast as they were deposited and so prevented the formation of moraines or made it impossible for them to be preserved. This was not true of the Chitina Glacier. As it retreated the great mass of rock carried by the ice was dumped in irregular piles over the valley floor. These morainal heaps have been subjected to the action of rain and frost, so that their surfaces have doubtless lost some of the original form. They are also overgrown with trees and other vegetation but aside from these changes probably appear much as they did when the ice melted. The imperfect drainage of the moraine-covered areas gave rise to numerous lakes and ponds that dot the valley floor. Such bodies of water are temporary and either will be filled by the deposition of material in them and the encroachment of vegetation on their shores or will be drained by the development of new streams.

The "rock glaciers" described on page 53 belong to the final stages of glaciation and are still in the process of formation. They are not characteristic of all glaciated areas but are known in many parts of Alaska. They constitute only a small part of the glacial deposits. Possibly they should not be included with glacial deposits, yet the fact that some of them merge into terminal moraines and have glacial ice at their heads gives ground for doing so. Although "rock glaciers" are relatively unimportant when compared with gravel and morainal deposits and considered in connection with the quantity of unconsolidated material they contain, yet they are noticeable topographic features. Little is known of their structure except what can be seen on the surface. They contain ice that fills the spaces between rock fragments, but the source of the ice and the relative quantities of ice and rock have not been determined.

The retreat of the glaciers gave the streams an opportunity to begin the work of adjusting their channels and grades to the changed topography. In many places the headwater grades of streams were much reduced by ice erosion or the valley heads were even so greatly lowered as to form rock basins. In other places the channels were filled with gravel and morainal deposits, so that the streams were dammed and forced to find new outlets. This they did by overflowing the barriers and removing the unconsolidated deposits or by cutting into the solid rock itself. The canyons of lower Kotsina and Kuskulana rivers were formed in this way, as were also some of the canyons in the valleys of small streams. More commonly, however, the canyons of the small streams had a different origin. They were formed at the mouths of hanging valleys, where the increased grade gave the streams power to incise their channels in the rock. Such canyons are well illustrated by Fall Creek, in Kluvesna Valley; by Peacock (Pl. IX, *A*, p. 7), Roaring, Rock, and Copper creeks, in Kotsina Valley; and by Nugget and Slatka creeks, in Kuskulana Valley. Each of these streams flows in a deep channel between rock walls at the place where it emerges from its own valley to the main river valley. The cutting of the canyons did not begin till after the ice level of the main valley was lowered below the mouths of the hanging valleys. It is still in progress and therefore is a part of the most recent history of the district.

Glaciation is the latest great cause that gave this district its present topography. The effects of glaciation are seen in many ways, as has been pointed out, yet weathering and stream erosion have already begun to destroy the features produced by it.

MINERAL RESOURCES.

By F. H. Moffit and J. B. Mertie, Jr.

The mineral resources of the Kotsina-Kuskulana district include gold, silver, and copper. Until recently copper held first place in the consideration of prospectors and miners, although placer gold is present in small quantity on Slatka Creek, and some effort to recover it was made in former years. The gold-bearing quartz vein on Benito Creek, however, and the silver-gold deposits of the North Midas Copper Co. on Berg Creek have brought these metals into greater prominence, and they give better promise of immediate production than the copper deposits.

The mineral production of the district to date includes only about two carloads of high-grade hand-picked copper ore shipped from Nugget Creek prior to 1916 and 160 tons of concentrates and hand-sorted ore shipped from the same place since that year, and in addition a small quantity of silver and gold produced at the mine of the North Midas Copper Co. There seems to be no prospect of further copper production from the district in the immediate future.

HISTORY OF MINING DEVELOPMENT.

Implements of copper are reported to have been seen in the hands of Copper River Indians by early Russian explorers and traders who visited the mouth of Copper River long before the mineral resources of Alaska were considered to be of value. These implements were said to come from somewhere on the Chitina (chiti, copper; na, river), but it was not until the exploratory expeditions of Allen[51] in 1885 and of Schwatka and Hayes[52] in 1891 that the reported presence of copper in Chitina Valley was confirmed. No efforts to investigate the copper deposits were made until 1898, when a few prospectors from the great company of stampeders who landed in Valdez Bay in the fall of 1897 and the spring of 1898 entered the Kotsina Valley. Other prospectors followed in 1899, and by 1900, when Schrader and Spencer visited the region, many claims had been staked and considerable development work was being done.

One of the first men to search for copper in the district was A. K. Crawford, who staked claims on Copper Creek and who now lies buried near his cabin on Kluvesna River. The first properties discovered on Elliott Creek were staked by H. C. Elliott and Chas. G. Hubbard in 1899. James McCarthy staked the Valdez claim on Nugget Creek in 1900. Among other early prospectors were A. L. Barrett and Adolph Ammann, Mr. Crawford's partner, who still retains his interests on Kotsina River. About 1907 Ole Berg staked the claims east of Kuskulana River that are now being developed for their gold and silver content. Many other well-known names of men who took an important part in the mining history of the district might be mentioned, for in the 20 years and more that have passed since the first discovery days a large number have had an interest in its possibilities for yielding copper and gold.

The Hubbard-Elliott Copper Co. early began the development of its property and by 1907 had obtained patent to many acres of ground. The holdings of the company, under the active promotion of H. C. Elliott, soon became one of the best known of Alaskan

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[51] Allen, H. T., Report of an expedition to the Copper, Tanana, and Koyukuk rivers, in the Territory of Alaska, in the year 1885, Washington, 1887.

[52] Hayes, C. W., An expedition through the Yukon district: Nat. Geog. Mag., vol. 4, pp. 117–162, 1892.

copper prospects. Mr. Elliott was killed by a snowslide while examining some exposures of copper ore on a steep slope near the head of Elliott Creek in 1911(?).

The Great Northern Development Co. began work on Kotsina River in 1906 with E. F. Gray as manager. Since 1907 this company has employed a larger force of men and has done more development work than any other company in the district. Most of its operations have been on Kotsina River and Clear Creek, tributary to Kuskulana River, but additional work was done on Iron Creek and near Kennecott, in the Nizina district. A snowslide in the winter of 1912–13 destroyed part of the plant on Clear Creek and killed several men. During recent years the company has confined its operations to assessment work on claims for which patents have not been received.

The Alaska Consolidated Copper Co. and its predecessors on Nugget Creek since 1900 have expended large sums of money in exploring the Valdez and neighboring claims, so that the extent of the ore body seems to have been fully determined and unfortunately is so discouraging to the owners that they have stopped work.

No data are at hand from which could be calculated the cost of mining exploration and prospecting in the district. It includes not only capital invested but the time and labor of men who had no capital. Doubtless the total is several million dollars.

CHARACTER OF THE COPPER DEPOSITS.

By J. B. Mertie, Jr.

DISTRIBUTION.

The copper deposits of the Kotsina-Kuskulana district occur on Kuskulana, Kotsina, and Kluvesna rivers and their tributaries at a number of different localities. The lodes have no definite geographic trend, and it is therefore inferred that the deposition of the ore minerals is not related to any major structural features.

Granodioritic, latitic, gabbroic, and basaltic rocks are present in the district, as described on pages 54–73, and although the ore deposits are genetically related to some of these rocks, yet at only a few localities—for instance, near the contacts with intrusive rocks—is this relationship direct and obvious.

In general the lodes lie along shear zones of small extent which, connecting with one another by an intricate system of fractures, have afforded suitable channels for the circulation of ore-bearing solutions and for the deposition of the copper minerals.

In the geologic column there is a decided localization of the deposits. Copper prospects have so far been found only in the upper part of the Strelna formation, in the Nikolai greenstone, and in the lower part of the Chitistone limestone. It is not to be expected that copper deposits would be found in Jurassic and younger rocks, for the mineralization is believed to antedate the deposition of such rocks. But the localization of the deposits in and near the Nikolai greenstone is an established fact and admits of more than one interpretation of the genesis of the ores.

TYPES OF DEPOSITS.

The copper deposits, with regard to their form and genesis, may be classified into two general types—the stringer lodes and the contact deposits. The stringer lodes are the more common.

The stringer lodes lie in shear zones, in large measure along fault planes and irregular fractures, and in places extend into the country rock. Most of them have been developed in the Nikolai greenstone, though the rocks of the Strelna formation have also been affected by the copper mineralization. One reason for this geologic localization of these deposits is the physical character of the lava flows that constitute the Nikolai greenstone and form a considerable part of the stratigraphic sequence in the Strelna formation. These beds of amygdaloidal lava have a high degree of rigidity, as compared with most sedimentary rocks, and the dynamic metamorphism of the region has developed in them a minimum of flexure and a maximum of internal shattering. If any part or all of the copper in the lodes has been leached from these basic lava flows, this fact should constitute an additional reason for the localization of the copper deposits in the greenstone.

Faults and cross faults, of indeterminate throw, cut the country rock at numerous places, and the resultant fissures and fractures, connecting with one another in an intricate system, have formed the channels along which the ore-bearing solutions have circulated and deposited the ores. The ore-bearing bodies in these stringer lodes range from tiny veinlets of copper minerals up to large irregular bodies of ore, as at the Bonanza mine, in the Nizina district. There has been, however, a certain amount of replacement, and hence the ore bodies at certain localities have been enlarged at the expense of the surrounding country rock. This condition is particularly prevalent at the intersection of two fissures or where ore deposition has taken place in the Chitistone limestone. The chief characteristic of these stringer lodes is their irregularity and lack of persistence at most localities. Only where ore deposition has taken place along well-marked zones of disturbance, or where a considerable amount of metasomatic replacement in limestone has occurred, are the stringer lodes ore bodies of commercial importance.

The contact deposits consist of disseminated copper minerals and some bodies of ore, which lie at or near the contact with intrusive rocks. In the Kotsina-Kuskulana district the contact mineralization seems to have taken place mainly along the peripheries of bodies of granodiorite.

ORE MINERALS.

The copper minerals that have been found in these deposits include bornite, chalcopyrite, chalcocite, malachite, azurite, native copper, silver-bearing tetrahedrite (possibly in part freibergite), cuprite, covellite, and chalcanthite, named roughly in their relative order of abundance. The principal ore minerals are bornite, chalcopyrite, and chalcocite, of which bornite and chalcopyrite are believed to be hypogene and chalcocite both hypogene and supergene at different localities. The terms hypogene and supergene are here used to indicate respectively the minerals deposited from hot ascending solutions and those formed from cold descending terrestrial waters. The term hypogene, as used, does not necessarily imply that the solvents were of magmatic origin. The terms primary and secondary are used strictly in their mineralogic sense, to mean only earlier and later mineral formation. The tetrahedrite, which carries some bismuth as well as silver, is also considered to be hypogene. Pyrite, in association with copper minerals, is found chiefly in the contact deposits, though also to a smaller extent in the stringer lodes. Malachite, azurite, native copper, cuprite, covellite, and chalcanthite are supergene everywhere. Chalcocite is in some places a primary and in others a secondary mineral.

STRINGER LODES.

TYPES.

Certain field observations, corroborated by metallographic study of the ores, appear to justify a separation of the stringer lodes into several types, which are distinct mineralogically and also with regard to their copper content. This division into ore types was conceived originally in the field, as a result of the observed absence of chalcocite in most of the deposits of bornite and chalcopyrite. Subsequently certain exceptions to this rule were explained by microscopic examination of the ores. Thus it was discovered that the chalcocite associated with bornite and chalcopyrite at the Valdez claim, on Nugget Creek, is in reality secondary—that is, a supergene mineral; and this occurrence therefore does not affect the validity of the following classification, which is intended to apply only to the mineral deposits formed by ascending thermal solutions.

This natural cleavage of the stringer lodes into more or less distinct types may be susceptible of more than one interpretation. The writer, however, is inclined to interpret this fact as evidence that the copper deposition occurred in several stages, which were distinct from one another both in time and in the richness in copper of the ore-bearing solutions.

The exact sequence of these several types has not been worked out in detail, but there is a certain basis for the belief that the mineralization that formed the stringer lodes began with the deposition of high-grade copper minerals and ended with a low-grade type of copper mineralization. Chalcocite, bornite, and chalcopyrite do not commonly occur together in this district as hypogene minerals, and this at once suggests that a certain differentiation of the ore-bearing solutions took place, resulting in mineralization in several stages. The occurrence of chalcocite with bornite does not furnish any positive evidence for determining the relative content in copper of the earlier and later ore solutions, for these two as hypogene minerals have so far been found either in separate deposits or intergrown in such a manner as to suggest strongly their nearly simultaneous deposition. Where bornite and chalcopyrite occur together the chalcopyrite appears to be later than the bornite, though both are believed to represent deposition from hypogene solutions. The facts, however, that chalcocite and bornite appear to be related to a certain extent and that chalcopyrite is always later than bornite certainly suggest that ore deposition in the stringer lodes began with the formation of the higher-grade deposits and terminated with the formation of the lower-grade deposits; and this suggestion has been adopted as a working hypothesis.

The following types of stringer lodes are accordingly recognized, named in their probable order of deposition: (1) Argentiferous tetrahedrite ores, (2) chalcocite ores, (3) bornite and bornite-chalcocite ores, (4) bornite-chalcopyrite ores, (5) pyrite-chalcopyrite ores.

With the present evidence it is not possible to prove definitely that the silver-copper ores were earlier than the other copper deposits. The only paragenetic information bearing on this point is that the silver-bearing tetrahedrite at one locality is clearly earlier than chalcopyrite, but these facts yield no information regarding the relations existing between tetrahedrite and either bornite or chalcocite. The assignment of the silver-copper ores to an early stage in the mineralization is therefore only an inference and not susceptible of definite proof.

With a view of determining the paragenesis of the several copper sulphides and the minerals associated with them, a number of sections of the copper ores were polished and examined under reflected light by R. M. Overbeck and the writer. The results of this work, accomplished under difficulties with regard to equipment and time, are by no means considered as a final analysis of the conditions of ore deposition in the district but are offered as contributory data to the study of the copper mineralization.

ARGENTIFEROUS TETRAHEDRITE ORE.

Tetrahedrite ore occurs only at one locality in the district—at the Silver Star group of claims on Kotsina River. The geology of this deposit is described on page 110.

The sulphide minerals present are tetrahedrite, chalcopyrite, galena, and a small amount of bismuth-bearing mineral, possibly bismuthinite. The tetrahedrite ore from this deposit is silver-bearing, from 0.08 to 2.4 per cent of silver having been recovered from ore containing quartz and other gangue material. From these figures it may be assumed that the tetrahedrite free of gangue is considerably higher in silver content; and as tetrahedrite carrying from 3 to 30 per cent of silver is commonly known as freibergite, it is rather likely that some of this tetrahedrite should properly be thus designated. Azurite and malachite are present as secondary products. The gangue minerals are quartz and barite.

The tetrahedrite in the specimen examined by reflected light is present as two coalescing stringers, which cut through a gangue of quartz and barite. Chalcopyrite occurs in a single small stringer, cutting across the tetrahedrite. Other small, almost microscopic veinlets of a highly reflecting mineral believed to be bismuthinite also intersect the tetrahedrite. Barite crystals project into the veinlet and are surrounded by later quartz and tetrahedrite, and the tetrahedrite replaces part of the quartz. The sequence of deposition appears to have been barite, quartz, and tetrahedrite, succeeded both by chalcopyrite and by the bismuth mineral. The azurite and malachite are of course supergene minerals, but all the other materials, including probably the chalcopyrite, are hypogene.

CHALCOCITE ORE.

Copper deposits representative of the pure chalcocite type of ore are lacking in the Kotsina-Kuskulana district but are developed farther east, at the Bonanza mine of the Kennecott Corporation. Moffit[53] is inclined to believe that the chalcocite at the Bonanza mine is a primary mineral, using that term strictly in the mineralogic sense. That is, the Bonanza chalcocite is believed to have been deposited as such in the Chitistone limestone and is therefore not considered to be an alteration product of some earlier copper mineral. The evidence is lacking, however, for determining whether hypogene or supergene solutions were the effective agents in the deposition of the ore. Yet in view of the observed differences in hypogene and

[53] Moffit, F. H., and Maddren, A. G., Mineral resources of the Kotsina-Chitina region, Alaska: U. S. Geol. Survey Bull. 374, p. 53, 1909.

supergene chalcocite in the Kotsina-Kuskulana district the writer is inclined to cite the Bonanza chalcocite as an example of hypogene mineralization, using that term in the sense previously defined. As a result of more recent work, Bateman[53a] is inclined to regard most of this chalcocite as hypogene but in part secondary, replacing bornite.

The nearest approach to the pure chalcocite type of ore in the Kotsina-Kuskulana district is at the Skyscraper group of claims, on Roaring Creek, the mineral occurrences on which are described on page 106. A hand specimen of this ore shows a mixture of crushed greenstone, largely epidote, with chalcocite and specular hematite, which cut the greenstone. Hematite is the most abundant mineral, though chalcocite is nearly as plentiful. A small amount of covellite is associated with the chalcocite. The ore minerals occupy some of the fractures in the crushed rock, though others are empty and intersect both the ore minerals and the greenstone. A polished section shows that chalcocite occurs with hematite in stringers in the greenstone or in relatively large areas free from the greenstone. It is of various shades of blue-gray. Etching shows that the chalcocite is present in crystals about 1 millimeter in size, in which grains of specularite are included. The covellite occurs in a few small patches in the greenstone and in several small stringers cutting the greenstone. It is probably derived from the chalcocite. It is believed that the chalcocite and the specularite were deposited simultaneously from the same ore-bearing solutions and that both are hypogene minerals. Of particular interest is the formation of chalcocite and hematite as independent minerals, instead of a copper-iron sulphide, such as bornite or chalcopyrite. A possible explanation of this anomalous condition is that the ore-bearing solutions carried insufficient sulphur for the formation of bornite, which has a theoretical content of about 28 per cent of sulphur, compared with about 20 per cent in chalcocite. The formation of bornite under the condition of a low sulphur content would necessitate the deposition of native copper, and although the possibility of the formation of primary native copper is by no means ignored, yet it may be that such action would not take place while conditions permitted the formation of a low-sulphur copper sulphide. The presence of specularite is considered good evidence that intense hydrothermal conditions existed at the time of the formation of this deposit. This inference is of particular value as indicating the formation of chalcocite, in this instance at least, from highly heated and presumably ascending waters.

Chalcocite accompanied by native copper has been observed at several localities, notably at the Snowshoe claim, on Roaring Creek,

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[53a] Bateman, A. M., and McLaughlin, D. H., Geology of the ore deposits of Kennecott, Alaska: Econ. Geology, vol. 15, pp. 66–67, January, 1920.

and also as float on the Skyscraper claim. It is by no means improbable that much of this chalcocite had the same origin as the chalcocite-specularite ore from the Skyscraper claim, though evidence adequate to prove this inference is lacking. The native copper has been considered to be a secondary mineral, derived from the associated chalcocite, but a certain amount of doubt is cast upon this interpretation in view of the conditions existing on the Skyscraper claim. If, as above inferred, the ore-bearing solutions had an abnormally low content of sulphur, a tendency might exist for the formation of copper sulphides low in copper and possibly also of native copper. Hence if the chalcocite in the ores carrying chalcocite and native copper is regarded as a primary hypogene mineral, it may be possible that some of the associated native copper had a similar origin.

BORNITE AND BORNITE-CHALCOCITE ORES.

Bornite is the most common copper mineral in the district. The ores of bornite grade on the one hand into bornite-chalcocite ores and on the other hand into bornite-chalcopyrite ores. None of the lodes here included consist exclusively of bornite, but where the chalcocite is known to be secondary in character the ore may consistently be considered as bornite ore, in conformity with the classification of the ores by their hypogene minerals.

Twenty or more localities are known where the copper minerals of the ores consist essentially of bornite and chalcocite. By the examination of several type specimens of such ores it has been determined that a large part of the chalcocite is secondary and probably supergene. Yet metallographic examination of one specimen, in conjunction with the data relating to its field occurrence, leaves little room to doubt that the chalcocite and bornite are intergrown as primary ore minerals. In view of this fact it is probable that the chalcocite in some of the other chalcocite-bornite ores may also be primary. This group of ores, then, on account of the intimate association of bornite with chalcocite, is made to include both the bornite and the bornite-chalcocite ores.

Pyrite is present in small amount in some of the bornite-chalcocite deposits, as on the George M. and Joe Dandy claims, on Surprise Creek, but specimens in which the pyrite was in contact with the bornite or chalcopyrite were not obtained. It is rather probable that the pyrite was not deposited contemporaneously with the copper minerals.

A specimen of bornite-chalcocite ore, taken from the Mineral King claim, near the head of Elliott Creek, was studied in reflected light to determine the relation existing between bornite and chalcocite. The hand specimen was porous and showed considerable oxidation, being covered with malachite. Quartz and sulphides were apparent on a freshly broken surface. On the polished surface bornite, chalcocite, and quartz are present, rather thoroughly mixed and in about equal amounts. Chalcocite occurs as stringers and as patches in the bornite and is of various shades of bluish gray. The large patches of chalcocite are rather deep blue and show distinct cleavage or parting lines, which may be inherited from bornite. Chalcocite also occurs as small patches in the bornite, whose relation to the bornite is not clear, and as stringers that very definitely cut bornite. Most of the chalcocite, then, seems to be later than the bornite. The genetic relations of the quartz and the bornite are not at once evident from their textural relations. There is a bare suggestion that the quartz may be later than the bornite, but this can not be proved or disproved without further study under higher powers of magnification than were available. From the texture of the ore the nature of the solutions which deposited the bornite may not be stated with certainty, but the bornite seems at least to be a primary mineral. It is probable that the secondary chalcocite was deposited from cold descending solutions.

A polished specimen of ore taken from the Valdez claim shows bornite, chalcocite, and a little calcite. The bornite makes up a large part of the ore. Most of the chalcocite occurs as stringers that cut the bornite. The calcite is present in a broad band cutting the bornite but is itself partly replaced by chalcocite. It is of interest to note that in many places where such chalcocite stringers intersect one another a granular intergrowth of chalcocite and bornite is developed which could not be distinguished by itself from a primary intergrowth of two minerals. Such textures, therefore, without reference to other available data can not be regarded as ultimate genetic criteria. In this instance the occurrence of chalcocite in stringers and the general megascopic appearance of the ore are considered sufficiently definite evidence that the chalcocite is secondary with respect to the bornite. The bornite is believed to have been deposited from a hypogene solution, although the polished section affords no evidence either for or against this idea.

The bornite-chalcocite ore at the Finch group of claims is rather remarkable in character, as well as in regard to its field occurrence. The ore body, described on page 133, consists of a disklike mass about 13 feet across and about 3 feet thick, standing nearly on edge. The ore consists of chalcocite, bornite, and quartz in varying amounts in different specimens. The texture resulting from the mixture of these three minerals resembles that of a granular igneous rock and suggests at once a primary intergrowth of the minerals involved. A polished surface of one specimen of the ore shows chalcocite, bornite, and quartz in approximately equal amounts. Quartz is present in rounded grains about one twenty-fifth of an inch in diameter and probably was the first of the three minerals to crystallize out. Chalcocite appears to be the next in order of deposition, and bornite last. The chalcocite is present in rather large crystals and is of various shades of blue-gray. The texture and association of the chalcocite, bornite, and quartz in this specimen suggest that they were deposited at much the same time from the same mineralizing solution.

BORNITE-CHALCOPYRITE ORE.

Bornite and chalcopyrite occur together to form the bornite-chalcopyrite lodes of the district. This group of lodes is rendered distinct by the almost universal absence from them of hypogene chalcocite.

The relation between the bornite and chalcopyrite is different from that between the bornite and chalcocite. Chalcopyrite where studied in association with bornite is observed to be secondary—that is, a replacement of bornite. For three reasons, however, it is believed that this replacement represents the action of hypogene solutions. In the first place, the character and form of the chalcopyrite are quite different from those of the chalcocite which has developed from supergene enrichment. The chalcopyrite is present in gash veinlets and also along the contact between bornite and gangue. At certain places these gash veinlets appear as discontinuous gashes oriented in a line across the bornite. Replacement deposits of this sort differ materially from the stringers of supergene chalcocite in bornite. In the second place, it should be remembered that this replacement represents an impoverishment and not an enrichment of the bornite ore, and this is not the sort of action usually accredited to cold descending solutions. Last of all, the absence of such replacement of bornite by chalcopyrite in the bornite-chalcocite ores shows that this particular replacement was not a universal process which bornite underwent, as would be expected if the bornite were replaced by a copper mineral deposited from supergene solutions.

It is inferred, therefore, that the bornite is the primary mineral and the chalcopyrite secondary, but that both are hypogene. This conception raises the question whether the bornite and chalcopyrite of these deposits were closely related in their deposition, perhaps as two phases of the same stage of mineralization, or whether they were unrelated, the chalcopyrite replacing the bornite in some later stage of the mineralization. It is of course possible for minerals from ore-bearing solutions to replace other minerals formed at an earlier stage, but the cleavage of the ores into rather distinct types shows a decided tendency of the copper minerals from different ore solutions to be deposited independently of earlier copper deposits. With this fact in mind, the writer is inclined to the belief that the bornite and the chalcopyrite of the bornite-chalcopyrite deposits were closely related in their formation, the chalcopyrite probably replacing the bornite shortly after its deposition and before the containing solutions had ceased to be active at the site of the deposit.

Pyrite, in greater or less amount, is present in association with the bornite-chalcopyrite ore at about one-third of the 20 localities where such ore was recognized. In the two specimens studied in reflected light pyrite was not observed in contact with either the bornite or the chalcopyrite, so that the paragenesis of these three minerals in this particular group is in doubt. It is probable that the pyrite, as in the contact deposits, was the earliest mineral to crystallize. Pyrite is entirely lacking in the chalcocite ores, is present rarely in the bornite-chalcocite ores, is present in about one-third of the bornite-chalcopyrite ores, and is universally present with chalcopyrite to form the so-called pyrite-chalcopyrite deposits, both in the stringer lodes and in the contact-metamorphic deposits. This increasing amount of pyrite in the lower-grade stringer lodes, the constant association of pyrite with chalcopyrite in the contact-metamorphic deposits, and the restriction of gold to the leaner copper ores constitute evidence that tends to relate the stringer lodes with the contact-metamorphic deposits and to connect both genetically with the intrusion of granodioritic rocks.

In polished sections of bornite-chalcopyrite ore from the United Verde and G & B claims the ore occurs as a stringer of bornite and chalcopyrite in the Nikolai greenstone. The gangue is largely quartz, though epidote, calcite, and jasper are present as alteration and replacement products in the adjoining greenstone. The polished surface shows chalcopyrite, bornite, chalcocite, and gangue. Chalcocite occurs only in two small irregular patches in the bornite. Stringers of bornite occur in chalcopyrite, and stringers of chalcopyrite in bornite. A study of the surface shows numerous undoubted examples of chalcopyrite replacing bornite, but no undoubted examples of the replacement of chalcopyrite by bornite. The stringers of bornite are thus probably residual stringers due to the incomplete replacement. The small areas of chalcocite are of doubtful significance. They bear no resemblance, however, to chalcocite occurring as a secondary supergene mineral resulting from the alteration of bornite, and it is assumed that they were primarily chalcocite, deposited in small amount with the bornite.

Bornite is replaced by chalcopyrite in a series of small gash veinlets, most of which are related to crevices in the ore and are apparently oriented with respect to crystallographic directions in the bornite at the contact between bornite and gangue, and chalcopyrite may replace quartz to some extent. Bornite and quartz were probably deposited at nearly the same time.

On the Valdez claim the bornite-chalcopyrite ore occurs with a gangue of quartz in a sheared greenstone. Bornite, chalcopyrite, chalcocite, quartz, and greenstone make up the polished surface. Bornite is the most abundant copper mineral, but chalcopyrite is nearly as abundant. In most of the sections bornite and chalcopyrite show mutual boundaries and consequently would seem to be contemporaneous. The presence of numerous small veinlets of chalcopyrite, however, throws doubt on their contemporaneity, for they indicate that at least some chalcopyrite is later than bornite. Bornite appears to be younger than the quartz in this rock. This intimate association of bornite and chalcopyrite is interpreted as further evidence of the close genetic relation existing between these two minerals and further justifies their grouping as a distinct type of ore.

PYRITE-CHALCOPYRITE ORE.

Ores consisting of pyrite with a greater or less amount of chalcopyrite have been observed at ten or more localities in the district. These are low-grade copper deposits, and on account of their occurrence as stringer lodes they do not form large bodies of ore like the contact deposits. As copper ores such deposits are of doubtful economic significance, but some of these lodes carry also gold and silver and have been prospected for these metals as well as for their copper content.

Genetically, such deposits differ from the contact deposits in the absence of the high-temperature minerals, such as garnet, magnetite, hornblende, and pyroxene, as well as in their mode of occurrence. It is not possible, therefore, to connect these ores directly with the intrusive bodies of granodiorite that were the source of the contact deposits, though it seems highly probable that the two types of deposits are related genetically.

The pyrite-chalcopyrite stringer lodes have not been studied in polished section, and therefore a certain amount of doubt exists with regard to the paragenesis of the two component sulphides. It is most likely, however, that the chalcopyrite is later than the pyrite, as in the contact lodes, but the choice remains of considering the pyrite as representing a distinctly earlier stage of the mineralization or of interpreting the pyrite and chalcopyrite as closely related minerals in the same period of mineralization. The latter hypothesis is favored as the more probable, and the grouping of the pyrite-chalcopyrite ores into a distinct type of deposits is considered to have a genetic significance.

CONTACT DEPOSITS.

The contact deposits are the product of a type of copper mineralization distinct genetically from that which formed the stringer lodes of this district. The contact deposits occur at or near the borders of masses of intrusive rock, mainly granodiorite, and consist of disseminated sulphides with some bodies of solid ore, which replace the country rock. The sulphide minerals are exclusively pyrite and chalcopyrite, and the resultant ore is considered to be a low-grade copper deposit. Contact-metamorphic minerals, such as garnet, magnetite, pyroxene, and hornblende, are present, but only locally in any large amount. Thus at the copper property of the Great Northern Development Co. on Clear Creek all four of these minerals have been found, but they are not to be seen except by a rather thorough examination of the ore. For this reason this group of deposits may be said to range from contact-metamorphic deposits proper, in which a considerable amount of igneous metamorphism of the country rock has occurred, to disseminated contact lodes, in which high-temperature contact minerals are only sparingly developed.

The contact-metamorphic deposits were formed under conditions of higher temperature and pressure than the stringer lodes. If the original source of copper in the stringer lodes was the Nikolai greenstone it is probable that the stringer lodes were formed by the action of circulating ground waters, which were heated and given a higher solvent power by granodioritic intrusives. Hence it is probable that the stringer lodes and contact-metamorphic deposits were formed more or less synchronously but at different localities. It is possible that in the later stages of intrusive activity both vadose and magmatic waters had a part in the formation of the stringer lodes, particlarly in the formation of the pyrite-chalcopyrite ores.

The contact deposits have been recognized chiefly at two localities in the Kotsina-Kuskulana district, at both of which they directly adjoin bodies of granodiorite. One contact deposit occurs at the head of Clear Creek along the west side of a large body of granodiorite that forms the bedrock in most of the upper valley of Porcupine Creek. The other zone of contact metamorphism lies on the southeast side of Kuskulana River, extending from MacDougall Creek to a point some distance southwest of Berg Creek. A small body of granodiorite that extends up the spur just northeast of Berg Creek to an altitude of 3,400 feet is the only intrusive rock visible in this vicinity, but the intensity of the contact metamorphism indicates that a large body of intrusive rock underlies the sedimentary formations at no great depth.

The mode of occurrence of the contact deposits in the upper valley of Clear Creek is described on page 71. A specimen of the ore from this deposit, taken from tunnel No. 3, shows a granular aggregate of pyrite, chalcopyrite, calcite, and flaky magnetite. The magnetite is of special interest on account of its micaceous appearance. Except for its brittle character and magnetic property, this flaky magnetite might easily be mistaken in the field for tablets of biotite, The pyrite is present as well-defined crystals but is very crumbly. Chalcopyrite occurs only in very small amount. A polished section of the ores shows that the pyrite is greatly crushed and broken and that chalcopyrite occurs between and partly surrounding the pyrite crystals. Chalcopyrite, together with calcite and magnetite, also cuts through the pyrite. The magnetite and chalcopyrite appear to be of about the same age, and both are definitely later than the pyrite. The magnetite in this specimen, in addition to other high-temperature minerals found in the ore, such as garnet, hornblende, and pyroxene, taken in connection with the proximity of the granodiorite on the ridge between Clear and Porcupine creeks, leaves little reason to doubt the contact origin of this deposit.

The deposits near MacDougall and Berg creeks are even more definitely of contact-metamorphic origin. Magnetite in bodies of considerable size occurs along this zone, and the country rock at certain localities is extensively silicified and garnetized. Thus at the Copper Queen claim the limestone country rock is altered to a chert, which is scarcely to be distinguished from the silicified limestone in the Strelna formation; and inside the tunnel, near the face, a body of rock composed essentially of garnet was intersected. The prospects along this zone are described in detail on pages 137–141. Ore from the Copper Queen claim was examined in some detail. One hand specimen consists of quartz and flaky magnetite, cut by a stringer of pyrite and chalcopyrite. In the polished section the mineral relations indicate that chalcopyrite was deposited later than pyrite, but the relation between pyrite and magnetite is not clear. The character of the ore and the geologic and mineral associations determine the contact-metamorphic origin of the material.

GENESIS OF COPPER ORES.

It is evident from the foregoing descriptions that the contact copper deposits originated as a result of igneous metamorphism along the edges of bodies of granodiorite. A good deal of uncertainty remains, however, regarding the origin of the stringer lodes. Several modes of origin seem possible, and two of these have degrees of probability so high that it is impracticable at present to offer evidence that will establish either one as the true source of these lodes. Moreover, the possibility exists that both explanations may contain some measure of truth, and the source of the copper may therefore be, to some degree, a composite one.

The genetic hypotheses held to be possible are as follows:

1. The copper was derived from the Nikolai greenstone by leaching, which was accomplished by meteoric waters of the deeper circulation, which were heated and perhaps charged with magmatic products by contact with underlying bodies of hot intrusive rocks.

2. The copper was derived directly from magmatic solutions, which were discharged from underlying magmas in the course of igneous intrusion, the magma being either of basic character and related to the Nikolai greenstone, perhaps as the underlying reservoir which supplied the basaltic material of the lava flows, or of granodioritic character.

The explanation that postulates the leaching of the copper from the Nikolai greenstone by cold descending meteoric waters, though possible, is not believed to give the true source of the copper lodes. The two following quotations from Lindgren [54] summarize adequately the writer's point of view with regard to this hypothesis:

> Waters of atmospheric origin doubtless have the power to dissolve many of the rarer metals contained in rocks, to carry them for considerable distances, and to concentrate them in places suitable for deposition; but unless it is aided by higher temperature at considerable depths below the surface, this power is probably not strong enough to produce important deposits of these rarer metals.
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> All basic lavas contain copper, but in many cases conditions were evidently unfavorable for the concentration of copper immediately after the eruption, and the rocks retained their copper until later opportunities for ore formation were offered. The existence of vast masses of such basic lavas near the surface, without any indication of copper concentration (e. g., the Columbia River lava or the basalts of the Hawaiian volcanoes), shows plainly that the ordinary surface waters at slight depth are not competent to dissolve and concentrate accessory metals contained in these rocks. A depth of perhaps a few thousand feet seems to be necessary, under the most favorable conditions, for waters of meteoric origin to extract the copper; though it is of course possible that such waters, when ascending in suitable channels, may deposit the dissolved copper at higher horizons.

The hypothesis that would explain the leaching of copper from the Nikolai greenstone through the action of heated ascending meteoric waters is the one which has been held by Moffit [55] to be the more probable, though he further states that "no evidence at hand warrants either affirming or denying a more deep-seated source for some of the copper-bearing solutions."

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[54] Lindgren, Waldemar, Mineral deposits, pp. 333, 382, 1913.

[55] Moffit, F. H., and Maddren, A. G., Mineral resources of the Kotsina-Chitina region, Alaska: U. S. Geol. Survey Bull. 374, pp. 50–54, 1909.

The strongest reason advanced for regarding the Nikolai greenstone as the source of the copper is the geologic localization of the stringer lodes in and near the greenstone, particularly in view of the universal presence of copper in basaltic lavas. Yet it is possible to explain this localization in other ways. The physical character of the Nikolai greenstone and the greenstone of the Strelna formation must also have been a potent factor in determining the sites of the deposits. On account of the superior rigidity and competency of the greenstones, dynamic metamorphism expressed itself in these rocks by crushing and shattering rather than by crumpling and folding, as in the adjoining sedimentary rocks. This alone might be judged to be sufficient reason for the localization. Also the presence of the body of Chitistone limestone near by, charging the underground water with lime and carbon dioxide, may have been instrumental in causing deposition of the copper ores in the underlying Nikolai greenstone.

The hypothesis that assumes a deep-seated source for the copper, related to the basic volcanism, can at best be only a partial explanation of the stringer lodes, for some of these are present in the Chitistone limestone, which was deposited after the formation of the Nikolai greenstone. However, if the Nikolai greenstone as originally poured out contained copper, it is not unreasonable to assume that the magma from which the lava was derived contained copper likewise. There is also evidence, as shown on page 58, that the later stages of the Nikolai volcanism were accompanied by the intrusion of basic diorites and gabbros, very similar in chemical composition to the basic lava flows. There is no good reason, therefore, why such intrusive bodies could not have discharged magmatic waters containing copper, in the process of their formation.

The alternative remains of considering the bodies of granodiorite the direct source of the copper-bearing solutions. The strongest single reason for this explanation is that the granodiorite has already been definitely connected with the copper mineralization in the contact-metamorphic deposits, but it does not follow that all the copper in this district came from a single source. It seems established, however, that the copper mineralization in the stringer lodes resulted from a process either identical with or closely related to the deposition of ore from magmatic waters at moderate depths. Calcite, quartz, and epidote are found in the gangue, and quartz and epidote are the common alteration products of the Nikolai greenstone near the lodes. The presence or absence of calcite in the veins can have little bearing on the genesis of the copper ores, for on account of the presence of the Chitistone limestone calcite might be expected to be present, either in deposits formed by meteoric waters or as renascent calcite in deposits formed by magmatic solutions. The quartz-epidote alteration of the greenstone, however, as shown on page 66, is a local alteration which took place subsequent to the regional chloritization of the greenstone and has been observed mainly in the vicinity of the stringer lodes. These data would indicate that the stringer lodes are the results of a special process and not the result of a regional leaching of the basaltic rock. Also the question arises as to the source of the quartz in this process of quartz-epidote alteration; and it seems more reasonable to look to the granodioritic than the basic rocks for it, particularly as silicification is a well-recognized feature of the contact lodes of copper.

It seems best at present to regard the source of the copper in the lodes as an open question. The solutions that deposited the copper may have been either of magmatic origin or of atmospheric origin and heated by contact with bodies of hot intrusive rocks, but it is believed that irrespective of the original source of the copper the deposits were formed by heated waters, migrating upward and being therefore classifiable, in effect at least, as hypogene solutions.

MINES AND PROSPECTS.

By F. H. Moffit.

SCOPE OF DESCRIPTIONS.

A considerable number of prospects within the Kotsina-Kuskulana district have been described at various times by the present writers and by other members of the United States Geological Survey who have studied the mineral deposits on these rivers and their tributaries. Some of the prospects are on claims on which assessment work has been done each summer for many years and are still held in the expectation of developing them into mines. Others have been definitely abandoned by their owners after it had been shown that they either were valueless or offered little hope of becoming productive properties, or when the money needed for development could not be obtained. Although inability to interest men with money in the development of a copper prospect may or may not be an indication of the possibilities of the prospect, still where development work has failed to show probable value or has demonstrated that it does not exist there seems to be no adequate reason for including the description of such prospects in this report, even though they have been included in former reports, unless they afford useful information regarding the structure, composition, or manner of occurrence of the ore bodies. A description of all the separate localities where copper staining was seen or where evidences of copper mineralization were examined would be tedious and of no practical value. The attempt will therefore be made to give an account of prospects which the owners themselves consider to be of sufficient promise to justify the expenditure of their own time and money in developing, of prospects that have produced ore, and of such others as yield information on the ore deposits.

All the copper properties where assessment or development work was carried on in the Kotsina and Kuskulana valleys were visited in 1914, many of them again in 1916, and part of those in the Kuskulana Valley in 1919. It is therefore evident that the following descriptions are not complete, yet it should be remembered that most of the prospectors, particularly those having property on the tributaries of Kotsina River, took advantage of the exemption granted during the war and did no assessment work, so that development on some prospects is now at practically the same stage as in 1916. This statement does not apply to certain tributaries of Kuskulana River where progress in mining development suffered no interruption other than that arising from the cost and scarcity of labor and materials. For convenience of description the different claims will be considered in accordance with their geographic location, beginning with Kotsina River valley.

KOTSINA AND KLUVESNA RIVERS.

GENERAL FEATURES.

The Kotsina and Kluvesna River drainage basins occupy the northern third of the area under consideration. The basalt flows of the Nikolai greenstone and the tuffs and basalts of the Strelna formation are extensively developed on these streams and show many indications of copper, which have been the objects of investigation by prospectors since 1898. A large number of claims have been staked at different times, and many are still held, although many others were given up after more or less work had been done on them. Nearly all the claims are now consolidated into a few holdings.

The upper Kotsina and the Kluvesna are not easily accessible even with the present improvement in transportation brought about by the construction of the Copper River & Northwestern Railway. Most of the supplies needed by prospectors are still brought in by sled in winter, although mail and small articles are now obtained from Strelna in summer either by way of Rock and Strelna creeks or by Roaring and Nugget creeks. The trail by way of Rock and Strelna creeks is much the better so far as footing is concerned, but it is used only for those walking and for pack horses. A wagon road down Kotsina River to Chitina or to some point on the railroad would be of great benefit to the prospectors living in the upper Kotsina basin.

Nearly all the copper prospects are on tributary streams at some distance from the Kotsina, and as a matter of convenience they will be described as groups determined by their location on the different tributaries.

KOTSINA RIVER.

A few prospects on Kotsina River that can not be referred to any of its tributaries require description, although not much except assessment work is being done on them. They include, among others, one or two prospects that, from their surface exposures, seem to be of greater interest because of their geologic relations than because of their economic value and have not received much attention from the miners.

The high rocky point on the north side of Kotsina River, 1½ miles above Rock Creek, consists of amygdaloidal greenstone (Nikolai) that contains native copper in sharp-cornered grains and small particles associated with chalcocite, from which the native copper is probably derived. A considerable quantity of quartz, both as small veins and lenses and as a filling of the vesicles in the basalt, was also introduced into the greenstone with the copper minerals. Native copper and chalcocite occur in the quartz and in the greenstone unaccompanied by quartz, although so much quartz is commonly present that the distinction may be of little consequence. Azurite and malachite are oxidation products, as is probably also a small quantity of cuprite on the copper. The native copper occurs chiefly on the brow and face of the point but is present likewise in the greenstone on the south side of Kotsina River opposite the point.

Two tunnels have been started 2,500 feet above the Kotsina on the east face of the spur east of the "rock glacier" 2½ miles above Rock Creek. They are on claims belonging to Thomas Larson. The country rock is amygdaloidal greenstone (Nikolai), filled with quartz amygdules and cut by veins and lenses of the same mineral. A zone of fracture along which the rock is stained with malachite crosses the greenstone at the place where the tunnels are situated. This zone has been traced for several hundred feet near the western tunnel and may extend a still greater distance, for there are indications of it in the high cliffs south of the tunnel.

Part of the claims along the south side of Kotsina River west of Roaring Creek that formerly belonged to the Great Northern Development Co. have been given up, but certain of them are retained in order to hold the water-right claims on Roaring Creek. Several short prospecting tunnels were driven by the company about 1906 or 1907 on certain of these claims on the south side of the Kotsina or close to the river bars half a mile west of Amy Creek. They uncovered no valuable copper deposits but illustrate a phase of mineralization in this district. The eastern tunnel is in a coarse-grained porphyry dike, 10 feet thick, intruded in gabbro and limited on both sides by faults that strike N. 30° W. and dip 80° W. The crushed zone on each side of the dike is mineralized with pyrite and is much stained with the oxidation products derived from it. At the western tunnel, a short distance downstream, the country rock is likewise gabbro intruded by a porphyry dike striking N. 35° W. At least one contact of the dike and gabbro is a fault contact—that on the west side. The dike is somewhat sheared, and the inclosing rock is much shattered near the fault and is mineralized with pyrite. A little copper stain is seen in the crushed rock.

Three other tunnels have been opened between the two localities just described. The same sort of mineralization took place in the rocks they penetrate, although the geology is somewhat different, for chert beds are associated with the gabbro. No work has been done on any of these tunnels in recent years. Annual assessment work, however, has been done on a tunnel three-quarters of a mile to the east, near the mouth of Roaring Creek.

COPPER CREEK.

Copper Creek was possibly the first stream in the Kotsina Valley to be prospected, for it was visited by the earliest explorers of the district. The stream joins Kotsina River a little more than 1½ miles below the mouth of Kluvesna River and is formed by three principal branches of nearly the same length, which head in the ridge between the upper Kotsina Valley and Elliott Creek. These branches from west to east are Copper Creek, the Middle Fork, and the East Fork. The heads of the three branches are crossed by a narrow belt of Nikolai greenstone, overlain by Chitistone limestone, which is thrust up over the younger Triassic shales on the north. Copper minerals have been discovered in the greenstone at numerous places and in the limestone near the greenstone at one place, in consequence of which a considerable number of claims have been staked on the three streams. All the claims with the exception of a small group of three were the property of A. K. Crawford and Adolph Ammann, but since Mr. Crawford's death they have been held by Mr. Ammann.

The three claims not belonging to Mr. Ammann are known as the Mullen group and belong to the Galena Bay Mining Co. They are on the west side of Copper Creek at an altitude of 3,700 feet and cover the contact of the limestone and greenstone. They also cover or are close to the fault contact of the limestone and greenstone with the black shales. Neither the greenstone nor the shale is exposed at the outcrop on the Mullen claim, and the copper minerals are in the limestone. A few yards east of the limestone are good exposures of greenstone along the creek, but the intervening rocks are covered with soil and vegetation.

The most abundant copper mineral is bornite. With it are associated a little chalcopyrite and the carbonates azurite and malachite. Azurite predominates over malachite, and in places the original bornite is entirely altered to azurite. Several short tunnels and open cuts have been made in the limestone, all within 200 feet of one another. They are scattered along the base of a limestone cliff or ledge that faces the creek on the east. Most of the work was done to fulfill assessment requirements and without a definite plan for prospecting the ground.

At the north end of the ledge the limestone is cut by a north-south fault along which is a zone of fractured limestone having a maximum thickness of 3 feet. The fractured limestone is cemented with calcite, especially near the fault. In the original exposure made by the open cut part of the limestone in this zone was almost completely replaced by bornite and chalcopyrite. The crushed limestone and copper minerals formed a poorly defined vein from 12 to 18 inches thick. This ore has since been largely removed, and a short tunnel was driven westward into the limestone. The tunnel, however, uncovered no ore.

About 75 feet to the south is another open cut where bornite is present as small isolated bodies in the limestone. The limestone is jointed, but the prominent fault of the northern exposure was not recognized. About 75 feet still farther south is another open cut and shallow pit. North-south faults cut the limestone, but the most prominent fault strikes east and dips steeply south. Masses of weathered limestone, stained with iron and copper, and bodies of bornite replacing the limestone are present near the faults and wherever the limestone was much fractured so as to allow the circulation of water. The bornite is accompanied by a little chalcopyrite and in part is oxidized to azurite and malachite. Malachite was more prominent than azurite on the weathered surface of the outcrops, but below the surface azurite prevails. The bornite is cut by many thin veins of azurite and in places contains small cavities lined with iron oxide or with azurite crystals.

Cave claim.—The Cave claim, the property of Mr. Ammann, is on the west side of Copper Creek, southwest of the Mullen, at the contact of the limestone and the greenstone. The Chitistone limestone at this locality is represented by only a part of its thickness. Moreover, it is cut by a westward-dipping fault that makes a slight angle with the bedding, along which the limestone has been thrust over on itself, thus causing the thickness to appear greater than it is. Azurite and malachite stain the limestone near the contact, and a tunnel was begun in the greenstone a few feet below the limestone to determine whether the staining was indicative of an ore body below. The tunnel was 50 feet long at the time of visit but had not reached the contact and showed no ore.

Peacock claim.—The Peacock claim is on the east side of Copper Creek directly opposite the Cave claim. A tunnel was started in the greenstone several hundred feet above the creek and is stratigraphically near the base of the limestone, although the limestone-greenstone boundary is 400 or 500 feet higher on the mountain slope. The greenstone is impregnated with bornite and a little chalcocite, which are indicated by surface staining at several places above the tunnel and are found in rock taken from the tunnel itself.

Mountain Sheep claim.—The Mountain Sheep claim is on the Middle Fork of Copper Creek, just over the top of the ridge from the Peacock claim. The greenstone contains bornite and a little chalcopyrite, indicated on the surface by malachite staining. Several open cuts and tunnels have been made in the greenstone a short distance below the limestone.

Forget-me-not claim.—The Forget-me-not claim is on the east side of the Middle Fork of Copper Creek near the limestone-greenstone contact and not far from the creek. An open cut in the greenstone shows chalcopyrite and at one place a little bornite.

Blue Bird claim.—The surface showing of the Blue Bird claim is the best showing of copper yet found on the claims in the basin of Copper Creek. This claim is on the east side of the Middle Fork, near the limestone-greenstone contact and considerably higher on the mountain slope than the Forget-me-not claim. The contact is a fault contact striking N. 60° E. and is cut by a cross fault which strikes N. 60° W. Bornite and a subordinate proportion of chalcopyrite were deposited in small irregular veins in openings of the fractured greenstone and replace the greenstone itself. A large open cut, in which considerable ore was piled, was made on this outcrop.

Montana Boy claim.—The Montana Boy claim is on the west slope of the East Fork of Copper Creek—that is, on the same ridge as the Blue Bird claim, which it either adjoins or lies near. Greenstone is the country rock, although limestone is present only a few feet distant on the south. The greenstone is crossed by a zone of fracture in which copper was deposited. Bornite is the chief copper mineral present, but a little chalcocite was found at one place near the limestone-greenstone contact. The development work on this claim includes open cuts and a short tunnel. Mr. Ammann reports that free gold was panned from an iron-stained quartz vein on either the Montana Boy or the Blue Bird claim.

Bunker Hill group.—The Bunker Hill group includes three claims on the east side of the East Fork. A tunnel is being driven in the greenstone on one of the claims about 300 feet below the top of the ridge between the East Fork and Pass Creek. This tunnel is near the great fault by which the greenstone was thrust over the Triassic shales on the north and must be several hundred feet stratigraphically below the Chitistone limestone, which crosses the ridge south of the tunnel.

The greenstone is shattered and is mineralized with bornite, pyrite, and chalcopyrite. Malachite and azurite are secondary products resulting from oxidation. The original copper and iron sulphides are associated with quartz and calcite where they occur as a filling in open spaces, but where they replace the greenstone the gangue minerals are absent or are inconspicuous.

AMY CREEK.

Extensive prospecting was done on Amy Creek for a few years, beginning about 1906, by the Great Northern Development Co., but many if not all of the claims on which that work was done have since been given up. Amy Creek is a short, steep stream west of Roaring Creek. It rises in a small glacier and throughout much of its length flows under ice or morainal deposits. All the valley except a small part at its upper end is in rocks of the Strelna formation—tuff, basalt, shale, and chert. These rocks are folded and faulted and locally are mineralized with pyrite, whose oxidation products color the weathered rock surfaces. Locally, presumably along zones of shearing that are identical with the original bedding and flow planes, the rocks are schistose.

Three tunnels, all within a quarter of a mile of one another and ranging from 1,300 to 1,600 feet above Kotsina River, were started on Amy Creek—two on the east side and the third on the west. They were driven in iron-stained outcrops of the basaltic country rock, which were thought to be the iron capping of weathered ore bodies, but they uncovered nothing except faulted and fractured country rock impregnated with pyrite and stained with copper.

ROCK CREEK.

The Warner prospect, near the mouth of Rock Creek, only a few hundred feet from the Kotsina, is the only copper prospect on Rock Creek except those on its eastern branch, Lime Creek. This prospect is patented property, and no work has been done on it for many years.

A tunnel 25 feet long was driven on the west side of the creek in the Nikolai greenstone near its contact with the overlying Chitistone limestone. The tunnel follows a crushed calcite vein deposited in a fault zone striking S. 35° W. The zone of crushed vein matter is from 3 to 3½ feet wide, but the zone of fractured greenstone bordering the calcite vein is much wider. The greenstone and vein matter are stained with malachite, and small irregular bodies of bornite and chalcopyrite are scattered along the zone of crushed rock.

LIME CREEK.

Lime Creek is the large eastern branch of Rock Creek. Almost all the area drained by Lime Creek is in the Nikolai greenstone, although the valley is walled in on the west by a great scarp of the Chitistone limestone which forms the ridge between Lime and Rock creeks. The boundary between the two formations is largely covered by glacier ice and talus débris but is exposed where it crosses Lime Creek, about a third of a mile above the mouth.

Copper minerals are known on Lime Creek near the point where the limestone-greenstone contact crosses the creek and have been prospected by tunnels and open cuts. These outcrops are on claims called the United Verde and the G & B and belong to Dick Gilleneau, Joe Bell, and A. L. Barrett.

A tunnel close to the contact on the south side of the creek discovered little more than copper stains and has had no work done on it for several years. The principal opening on the north side of Lime Creek is a tunnel, between 200 and 300 feet above the stream, in greenstone impregnated with bornite and chalcopyrite. Bornite predominates greatly over the chalcopyrite and is associated in places with quartz and epidote. In places, however, the bornite, which forms small lumps and lenticular bodies in the greenstone, is unaccompanied by gangue minerals.

Several similar exposures of bornite in greenstone are made in open cuts near by. The greenstone is cut by faults or fractures that strike N. 15°–35° E., along which veins of quartz and bornite were formed or the greenstone itself was replaced.

ROARING CREEK.

Roaring Creek is the second large creek coming into Kotsina River above the mouth of the Kluvesna and heads against Nugget Creek on the east and Rock Creek on the west. Its valley, a typical U-shaped glacial valley in which several small glaciers still remain, is of the hanging-valley type and lies nearly 1,000 feet above the wide gravel flats of Kotsina River. The creek has cut a deep canyon in the lip of this valley, through which it descends to the Kotsina. A steep trail on the east side of the canyon leads from the bars of Kotsina River up into the valley of Roaring Creek, and another trail, suitable for foot travel during part of the summer, passes over the high ridge between Roaring and Nugget creeks to the Kuskulana Valley.

Roaring Creek offers a good opportunity for the development of a small water power, inasmuch as the flow of water, which is derived in large part from melting snow and ice and thus is not entirely dependent on the summer rainfall, is fairly constant. Furthermore the steep grade at the mouth of the creek makes it easy to apply the water in a suitable generator.

Practically all the rocks of the Roaring Creek valley belong to the Strelna formation and the Nikolai greenstone. Several small patches of limestone and sandstone on the tops of the ridges east of the creek are the only exceptions. These rocks have been much faulted and fractured, and in the passageways thus provided mineral-bearing solutions have made numerous deposits of copper minerals. Nearly a dozen small tunnels have been started in such mineral deposits in different places throughout the valley, but a number of the claims represented by these tunnels are now abandonded.

The Skyscraper group comprises six claims belonging to Adolph Ammann. Two of them lie end to end on the axis of the ridge north of Skyscraper Peak; the other four follow the base of the Chitistone limestone, which forms the peak, in such a way that two claims lie on the Roaring Creek side of the ridge and two on the Peacock Creek side, with Skyscraper Peak between. From north to south the two claims on the ridge are the Snowshoe Extension and the Snowshoe, those east of the peak are the Skyscraper and the Morning Star, and those west of it are the West Skyscraper and the Castle.

The copper deposits on these claims consist chiefly of chalcocite and subordinate native copper. Most of the exploration and development work is being done on the Snowshoe claim, where a tunnel considerably over 100 feet long has been driven on the east side of the ridge a short distance below the top. The greenstone flows at the tunnel dip steeply east-northeast and contain scattered grains of chalcocite.

A short tunnel 350 feet below the base of the limestone, probably on the West Skyscraper claim, uncovered a lens of chalcocite about 6 inches thick in the greenstone. Such lenses and the chalcocite disseminated through the greenstone probably occur in a zone of fracturing of considerable width, for chalcocite in grains and small particles is scattered through the greenstone at many places on the claims along the ridge and below the limestone and does not seem to be directly connected with major faults or fractures but to be disseminated through rocks broken by a great number of joints and minor fractures. The native copper presumably results from the alteration of the chalcocite. It occurs without gangue minerals as rough, branching bodies in the greenstone on the Snowshoe Extension, Skyscraper, and Castle claims. The copper indications in the vicinity of Skyscraper Peak continue around the mountain slope into the valley of the east branch of Roaring Creek, where at least half a dozen short tunnels have been driven.

The other prospecting tunnels on Roaring Creek are all, with one exception, in rocks of the Strelna formation. A tunnel on the east side of the creek, a short distance above the canyon, is probably in the Nikolai greenstone. The claim on which it is situated has been abandoned for a long time, but the rock at the tunnel contains pyrite, chalcopyrite, and bornite in small quantity. Another tunnel, on the west side of the creek near the forks, is in a dark-colored, much altered granular rock, probably a gabbro, but shows nothing of value. Two other tunnels have been driven on a ridge between two small gulches on the west side of Roaring Creek, half a mile above the forks. The lower tunnel is 200 feet above the creek in fine-grained basalt of the Strelna formation and was 50 feet long when visited. A fault striking N. 50° W. and dipping 30° SW. forms the roof of the tunnel and is cut by a vertical fault that strikes N. 30° W. East of the tunnel is 40 feet of light-yellow shaly rock, succeeded by gabbro and thin-bedded cherts. Iron stains are abundant, but not much copper was seen.

About 800 feet higher on the ridge to the west is another tunnel, also in rocks of the Strelna formation and between 300 and 400 feet below the boundary of the Nikolai greenstone. On the ridge above the tunnel copper float, containing the minerals chalcocite, native copper, and malachite, associated with quartz and epidote, was found in the Nikolai greenstone area.

Another tunnel is driven in the south side of a gulch coming into the creek from the west a little more than half a mile above the forks. Two others, one of which has been abandoned, are half a mile farther up the creek, one on each side, at an altitude of 4,400 feet.

PEACOCK CREEK.

Peacock Creek, on the northeast border of the area mapped, is a southerly tributary of Kotsina River. The rock exposed in its valley is chiefly Nikolai greenstone but may include some members of the underlying Strelna formation and is cut by numerous porphyritic dikes, apophyses of the granodiorite mass exposed at the mouth of Peacock Creek and in the mountains opposite, on the north side of the Kotsina. Indications of copper have been found at several places on Peacock Creek, and in the early days of the district considerable prospecting was done here. The prospects, however, were disappointing, and most of the claims have been given up.

SHOWER GULCH.

Shower Gulch is near the end of the small glacier that feeds the southern branch of Kotsina River. It is therefore somewhat outside the limits of the area shown on the map (Pl. II, in pocket), but its description is included with those of other prospects on the Kotsina. It is a steep canyon-like gulch scarcely more than a mile long, lying south of the glacier, and at its lower end is easily accessible from the gravel bars of Kotsina River.

Shower Gulch has carved its canyon in basaltic lavas of the Nikolai greenstone, which in places contain native copper. At a point in the gulch about 500 feet above the bars of the Kotsina the greenstone is made up of distinct flows which strike east and dip about 20° S. These flows range in thickness from 5 to 25 feet or more. The upper part of each flow is amygdaloidal; the middle and lower parts are dense and without amygdules.

Two open cuts expose the copper-bearing greenstone. At the lower open cut, near the stream, is a lava flow 6 feet thick, whose upper third was originally vesicular but is now filled with amygdules of quartz and epidote. The greenstone is cut by a well-defined vertical north-south fault but does not appear to be unusually fractured. Native copper in leaves, grains, and slugs is deposited in the amygdular part of the flow and is practically the only copper mineral visible, although a little chalcopyrite was seen in a specimen of greenstone largely replaced by quartz and epidote at this open cut. Native copper is not confined to the particular lava flow mentioned but yet is not present in all the flows. The upper open cut is 300 feet above that just described and differs from it, so far as copper minerals are concerned, only in the presence of a little chalcopyrite accompanying the native copper.

Four claims were held on Shower Gulch at the time the prospects were visited in 1914 and were the property of J. E. Drake and H. B. Grenig.

SURPRISE CREEK.

The Surprise Creek group includes nine claims on Surprise and Sunshine creeks, in the upper Kotsina Valley. They lie north of Sunshine Creek between Surprise Creek and the north branch of Kotsina River and are thus outside the boundaries of the area mapped. The Laddie, Sheehan, and Hubbard claims, described in a former report,[56] are included in the group but received new names when they were restaked a number of years ago and accordingly are designated by the new names here.

Surprise Creek is only 3 miles long and flows southward into Kotsina River. The greenstone of this vicinity is intruded by a mass of granodiorite, which is prominent in the area between Kotsina and Kluvesna rivers. Surprise Creek is in the granodiorite area close to its eastern boundary. The copper deposits, however, are in the greenstone.

[56] Moffit, F. H., and Maddren, A. G., Mineral resources of the Kotsina-Chitina region, Alaska: U. S. Geol. Survey Bull. 374, p. 57, 1909.

A fault zone, whose general course is northeast, cuts the greenstone high on the mountain east of Surprise Creek. This zone is well defined and may have caused considerable displacement in the greenstone, although no evidence of the amount of displacement, other than the general appearance of the fault, was obtained. The course of the fault is seen on the mountain to the northeast and is said to be plain as far as the glacier at the head of the Kotsina.

Six claims lying end to end have been staked along the fault zone. The claim at the southwest is the George M. (formerly Sheehan). That next to it is the Joe Dandy (formerly Hubbard). Northwest of the George M. are the Drake and Grenig claims, lying end to end, and north of them is the True Blue (formerly Laddie). The long dimensions of all the claims are parallel or approximately so.

Since these claims were visted by the writer, in 1907, a tunnel 135 feet long has been driven on the Joe Dandy claim, in addition to other assessment work necessary to hold the property. The tunnel is not long enough to reach the copper-bearing fractures, and neither it nor the assessment work has brought to light much that is new regarding the deposits. There is therefore little to add to the earlier description.

True Blue claim.—Between Surprise and Sunshine creeks is a steep gulch running down from the north. On the west side of this gulch and nearly 3,000 feet above Kotsina River is the True Blue claim. A very close grained grayish "greenstone" forms the country rock and is cut by a fault striking N. 20°-30° E. and dipping about 45° NW. Along the fault is a zone of crushed country rock ranging in width from 2 to 3 feet, in which is a quartz vein 18 inches thick. Besides quartz there is a small amount of calcite. The vein carries chalcocite accompanied by a little bornite and chalcopyrite. In places the percentage of copper minerals in the vein is high, but they are not distributed uniformly through it. A line of prospect holes extends along the vein for a distance of 200 feet.

George M. claim.—At the George M. claim, 200 feet higher than the True Blue and a little farther east around the mountain side, the greenstone is cut by a fault striking N. 45° E. and dipping 45° NW. This fault resembles the True Blue fault in being accompanied by a zone of crushed rock, but the zone is here somewhat wider, ranging from 3 to 4 feet. A small quartz vein is exposed, in which the copper minerals are chalcocite, bornite, and a little pyrite. The small veins of chalcocite cutting the quartz are in places half an inch thick.

Joe Dandy claim.—About 300 feet east of the George M. claim and a little higher on the mountain the vein of the Joe Dandy is exposed in two open cuts. The vein is almost vertical and strikes N. 40° E. In the more southerly open cut there is a vein of white quartz ranging in thickness from 4 to 8 feet and carrying chalcocite, bornite, and pyrite, which are named in the order of their abundance. A strongly marked fault with 3 inches of clay seam defines the north wall of the vein. At 8 feet from the vein on the southeast is a second vein or lens of quartz 10 inches thick, also carrying chalcocite. Between the two veins is crushed greenstone. Nearly 200 feet to the northeast along the strike an open cut 40 feet long and 25 feet deep has been made across the vein. The fault is again seen along the north wall, but the single large quartz vein exposed in the other cut is here represented by many smaller veins of lenticular form 12 inches in maximum thickness. Chalcocite and bornite are the copper minerals.

Nearly 1,000 feet farther northeast a well-marked fault with a zone of sheared greenstone crosses the ridge between Kotsina River and the Joe Dandy claim and is said to extend as far as the glacier from which this branch of the Kotsina springs. There is little doubt that this fault is the continuation of that crossing the Joe Dandy claim.

SILVER STAR GROUP.

The Silver Star group is of interest because of the silver content of its mineral deposits rather than because of the copper content. This small group of claims is on a short stream tributary to Kotsina River from the north about 2¼ miles above Rock Creek. The Silver Star claim is at the head of the stream, a little more than a mile from the gravel bars of the Kotsina and 2,400 feet above them.

These claims are near the boundary of the Nikolai greenstone on the west and the tuffs and fine-grained basalts of the Strelna formation on the east. The mineral deposits are most probably in the older rock—that is, the Strelna formation—but the boundary line can not be drawn with precision, and possibly the deposits extend up into the Nikolai rocks. Not more than a third of a mile east of the Silver Star tunnels is the western margin of the diorite mass that forms Granite Mountain. The granodiorite boundary on the north slope of Kotsina River in this vicinity extends to the southeast, and the intruded rocks on the southwest are much fractured and faulted and considerably mineralized. As a result of these conditions the rocks exposed in the gulches and on the hill slopes immediately southwest of the granodiorite area are highly colored with iron oxide.

The metallic minerals on the Silver Star and adjoining claims are tetrahedrite, galena, azurite, and malachite in a quartz gangue. They occur as veins along fracture planes in a shear zone.

The lower tunnel on the Silver Star claim is 2,400 feet above Kotsina River. It has a total length of 260 feet. For 170 feet the main tunnel follows a course N. 20° W., but it has two branches at 150 feet, one going N. 80° W. for 30 feet and the other after a slight offset resuming practically the original course of the tunnel for 60 feet. This tunnel and its branches follow faults that dip rather steeply west, except the fault striking N. 80° W., which dips 30° N. The hanging wall of the main tunnel and right branch is dense, hard basalt. The footwall is soft broken rock, whose original character is not fully evident. Amygdaloidal greenstone and a greatly altered porphyritic intrusive, probably pyroxenite or peridotite, crop out a few steps west of the tunnel. They are faulted to their present position and are greatly shattered. Tetrahedrite, the principal metallic mineral exposed in the tunnel and surface outcrops, occurs in veins along the principal fault and in minor fractures that extend into the hanging wall.

The upper tunnel is 75 feet higher and a short distance up the slope. It is only 20 feet long but starts in an open cut where nearly as much work has been done as in the tunnel itself. The country rock is fine-grained greenstone, so much broken that good fresh hand specimens are hard to get. Several faults cut the greenstone; the principal fault is that which the tunnel follows and which contains the metallic minerals. It is filled by a metalliferous vein of quartz and country rock 30 inches thick and dips steeply N. 30° E. The copper minerals are silver-bearing tetrahedrite, malachite, azurite, and galena.

Between the two tunnels is an open cut with a vertical fault striking N. 10°–20° W. and another fault dipping 60° W. North of the upper tunnel on the mountain slope and on the top of the ridge are veins of quartz containing the same minerals as are present in the tunnel. The upper tunnel and a series of open cuts, together with the discovery outcrop, seem to indicate a vein or veins striking about north and dipping west. The claims are staked on this assumption. It is quite possible, however, that the mineralization took place in overlapping fractures that make a small angle with a zone of fracturing extending in a southeasterly direction, parallel to the granodiorite contact. In support of this suggestion is the fact that similar veins with northerly strike are present on some of the gulches near the granodiorite area. Two-thirds of a mile southeast of the Silver Star tunnels, at the border of the granodiorite area and 1,300 feet above Kotsina River, the granodiorite is cut by veins containing tetrahedrite, malachite, azurite, and barite, which strike N. 15° W. and dip 40° W. Azurite is rather plentiful. This zone of fissuring and veining extends up the gulch nearly to the ridge above.

Veins like those at the Silver Star claim are exposed in an open cut south of the tunnels and about 1,000 feet below them. This cut is between 200 and 300 feet west of the creek and exposes a quartz vein, containing galena, in much sheared greenstone. The exposure is poor and observations are difficult to make, but apparently the vein strikes north or north-northwest. The rock is stained with iron and copper whose original form was not evident. No tetrahedrite was recognized.

Neil and Thomas Fennesend, the owners of the claims (1916), reported that a large number of assays had been made on samples taken from the veins and that the returns showed silver ranging from 25 to 700 ounces to the ton and copper from 1 to 32 per cent. Bismuth is a constituent of one of the minerals, probably the tetrahedrite.

KLUVESNA RIVER.

Lost Cabin group.—The Lost Cabin group, belonging to Adolph Ammann, consists of six claims lying end to end and extending northward along the contact of the Chitistone limestone and the Nikolai greenstone from the flats of Kluvesna River to the top of the ridge west of the river. Most of the copper indications are in the greenstone a few hundred feet or less below the limestone, but in places copper is present near the contact. It does not appear in the limestone.

Chalcocite, bornite, and chalcopyrite are the copper minerals. At the lower or south end of the group the copper mineral is bornite; higher up, toward the north, it is chalcocite; and still higher and near the limestone it is chalcopyrite. The bornite and chalcocite are disseminated through the greenstone without notable gangue minerals. Where chalcopyrite is present the greenstone is stained with iron oxide.

Four tunnels and several open cuts have been made on the property. The tunnels are at the south end of the group and were started to prospect the vicinity of the contact. None of them, however, have yet been driven far enough to reach the contact.

Good Enough group.—The Good Enough group, owned by Mr. Ammann, is on the west side of Kluvesna River only a short distance west of Fall Creek. This locality is at the boundary of the Nikolai greenstone and the underlying Strelna formation. The country rock consists of fine-grained basalt and tuff. It is faulted and fractured and at this place is mineralized with native copper and chalcocite associated with quartz and calcite. Cuprite, malachite, and azurite are present in small quantity. Assessment work has been done on three claims of the group and is represented by two tunnels. The longer and older tunnel is on the northeast side of a deep gulch, 500 feet above the trail to the camp on Fall Creek and more than 1,500 feet above Kluvesna River. It was driven in a northwesterly direction for about 70 feet through much fractured greenstone and includes one crosscut. Several prominent faults which strike N. 35°–45° W. and dip 50° SW. cut the greenstone. These faults with the joints and other fractures gave opportunity for mineral-bearing solutions to move through the greenstone.

The copper minerals in the deposits are native copper, chalcocite, and a minor quantity of cuprite, malachite, and azurite. These minerals form veins with quartz and calcite, make up the amygdules of the greenstone, and replace the greenstone itself.

The rock in which the tunnel was driven was so greatly shattered that the roof caved, making the work difficult and dangerous, and a new tunnel was started on the south side of the gulch several hundred feet away.

FALL CREEK.

Fall Creek is the largest tributary of Kluvesna River and joins it from the north 2 miles below Kluvesna Glacier. Only half a mile of the lower end of the creek is within the area represented by the topographic map (Pl. II, in pocket), and none of the copper claims on the creek are within it.

Fall Creek lies in an area of rocks belonging to the Strelna formation, which here consists chiefly of tuff and fine-grained basalt. The copper minerals in the prospects on the creek are bornite, chalcocite, native copper, malachite, azurite, cuprite, and a brittle black carbonaceous substance which contains copper oxide.

All the copper prospects on Fall Creek belong to Adolph Ammann. They are confined to the vicinity of two small western tributaries called Trail Creek and Flimflam Gulch and to the top of the ridge between Fall Creek and the lower end of Kluvesna Glacier. The first group includes four claims, three of which, the Sunset, Sunrise, and Homestake, lie end to end in a north-south direction and extend southward from Flimflam Gulch across Trail Creek to the mountain slope south of Trail Creek. The fourth claim, the Newhome, is nearly perpendicular to the south end of the Homestake claim and extends eastward down the slope toward Fall Creek. The copper prospects of these four claims have been explored by open cuts and several short tunnels. All are in rocks that are mainly tuffaceous but include sheets of amygdaloidal greenstone.

A short tunnel on the south side of Flimflam Gulch about half a mile from Fall Creek is driven along a north-south fault in amygdaloidal greenstone, which is fractured and contains small veins of quartz and calcite. Malachite stains the surface exposures of the greenstone, but both malachite and azurite are present in fractures in the rock. Cuprite is also present, and between the blocks of greenstone along the fault there is in places a filling of the black carbonaceous copper-bearing material.

A short tunnel on the north side of Trail Creek, on the Sunrise claim, exposes a vertical north-south fault in amygdaloidal greenstone, cut by small light-colored fine-grained porphyritic dikes and by quartz veins containing a little bornite. Native copper is also present in an outcrop near the creek.

South of Trail Creek and the tunnel just mentioned and 375 feet above them is a tunnel on the Homestake claim. It is driven south along a vertical fault in greenstone stained with malachite. Greenstone containing native copper is exposed in the ledge 25 feet above the tunnel mouth and about the same distance south of it. The greenstone also contains chalcocite and the black carbonaceous copper-bearing substance.

The discovery outcrops of the Newhome claim are near the tunnel south of Trail Creek but are farther around on the slope toward Fall Creek. At this place the loose surface deposits were washed away with a stream of water so as to expose the bedrock, which here is much fractured and is veined with quartz containing bornite and chalcopyrite. A tunnel was started a few feet lower on the slope toward Fall Creek to undercut the veins exposed in the open cuts but had not reached them at the time of visit.

The Hidden Treasure claim is on the mountain top east of Fall Creek, about 1½ miles from the camp at the mouth of Trail Creek, and has been prospected by several open cuts and a tunnel, in which native copper, chalcocite, and bornite have been disclosed. Bornite and chalcocite occur together at the south end of the claim; chalcocite and native copper at the other end; and between are chalcocite and native copper in quartz. The tunnel was started to explore the bornite and chalcocite at the south end of the claim.

MINERAL CREEK.

Mineral Creek is a tributary of Kluvesna River nearly opposite Fall Creek. It heads in the granodiorite area of Granite Mountain and flows northwestward through a steep gulch to the flats of the Kluvesna. A narrow ridge separates it from the gulch on which the Silver Star group is situated.

The country rock includes chert and tuff interbedded with lava flows and belongs to the Strelna formation. In general the strike of the rocks along the lower part of the creek is almost north, and the dip is about 45° E. The cherts, tuffs, and lava flows are intruded by diorite and by more basic, dark-colored granular dikes or sills. Some of the intrusives, especially the light-colored fine-grained dioritic rocks, contain much disseminated pyrite. Both the intruded and the intruding rocks are cut by numerous faults, along which were deposited quartz veins mineralized with pyrite, chalcopyrite, and in places a little chalcocite.

Half a dozen tunnels have been started by different prospectors on outcrops of iron and copper sulphide minerals, chiefly pyrite and chalcopyrite, along the creek, but most of the recent work has been done on the Valdez group of claims. The Valdez group, which belongs to A. L. Barrett, Ed. Young, and Jake Nafsted, includes six claims, all but one of which are on the southwest side of the creek.

The principal tunnel is on the southwest side of the creek about a quarter of a mile from the timbered flats of Kluvesna River. The rocks at the tunnel are chiefly diabase and are cut by many faults. At the mouth of the tunnel is a north-south fault which dips 50° E. A few feet upstream another fault strikes N. 40° E. and dips 75°–80° W. The tunnel extends S. 25° W. for 50 feet and follows a probable bedding or flow plane, which is also a fault plane, mineralized with pyrite and chalcopyrite in crushed quartz and country rock. The vein reaches a thickness of 4 feet at one place. At 50 feet from the entrance the vein is faulted off or offset by a fault, which strikes N. 65° E. and dips 70° NE., and from this point the tunnel was continued as two branches, one extending south a short distance and the other bearing S. 70° W. for 50 feet. The numerous fractures in the tunnel contain veins of quartz, pyrite, and in places chalcopyrite, but the pyrite predominates. It contains both gold and silver in addition to copper. Assays are reported to show a gold content of $9.75 and a silver content of 3 ounces to the ton.

A short tunnel on the Valdez No. 1 claim, 350 feet higher than the tunnel already described and near the creek, shows veins of pyrite in calcite and quartz. The vein contains a little gold.

About 200 feet higher than the Valdez No. 1 tunnel is a short tunnel on the northeast side of the creek, on a vein of mineralized quartz. A strong fault at the mouth of the tunnel strikes N. 50° E. and dips 80° W. At 50 feet still higher are two mineralized zones, about 30 feet apart, which follow the bedding or flow planes of the country rock and on which a little work has been done.

Three short tunnels have been driven on two claims not belonging in the Valdez group on the northeast side of Mineral Creek, opposite the Valdez and Valdez No. 1 claims. They lie along the creek at altitudes differing by about 75 feet. None of them discovered copper prospects of promise.

A vein of quartz containing pyrite, chalcopyrite, and bornite was found near the head of a small northern tributary to Mineral Creek. The vein is exposed in a short tunnel 4,600 feet higher than Kluvesna River and is somewhat difficult to reach because of the ruggedness of the mountain. It is about 18 inches thick and was deposited in a fault in the greenstone country rock. A gold content of $60 to the ton is reported to have been shown by assays.

ELLIOTT CREEK.

Elliott Creek is more widely known than any other copper-bearing locality in Chitina Valley except Kennicott. It was one of the creeks first prospected and ever since has been kept continually before the public interested in Alaskan copper deposits.

Elliott Creek is a tributary of Kotsina River. It heads against the west branch of Strelna Creek and follows a course parallel to Chitina River for most of its length. The stream is approximately 10 miles long, but only the upper 5 or 6 miles is of interest on account of its copper. This part lies in a straight, narrow valley, practically all of which is above timber line. The lower part below timber line flows in a deep rock-walled canyon. The grade of the creek between the lower camp, near the mouth of Five Sheep Creek, and the upper camp, at the mouth of Rainbow Creek, a distance of 2 miles, is approximately 375 feet to the mile, for the altitudes of the two camps are 2,858 feet and 3,611 feet respectively. The average grade of the upper part of the creek for 3 miles above the upper camp is about 460 feet to the mile, but the grade in the last mile is considerably steeper than this. Elliott Creek receives its water during most of the summer from melting snow and ice. The head and south side of the valley accumulate a great deal of snow during the winter and are so well protected from the direct sun that the snow there melts slowly and furnishes water long after that on the north slope of the valley is gone. Considerable water power is available and could be obtained advantageously by making use of a power site in the canyon.

The camps on Elliott Creek are connected with Strelna by a pack trail which crosses the west end of the ridge between the creek and the Chitina Valley and joins the Kuskulana road about 2 miles north of Strelna. Parts of this trail were only recently laid out, having been relocated in order to avoid swampy ground traversed by the former trail. Another trail to Elliott Creek follows Strelna Creek to the head of one of its western branches and crosses a high pass between the two streams. This trail is impassable in early summer, because of snow, and is not commonly used at any time. The distance by the regular trail from Strelna to the lower camp on Elliott Creek is about 14 miles. Strelna is now the post office for Elliott Creek and the point from which all supplies are obtained in summer. The old trail across Kotsina River to Billum's Crossing, on the Copper, has not been in use for several years.

Copper claims were first staked on Elliott Creek in 1899 by H. C. Elliott and Chas. G. Hubbard. The number of claims was increased from time to time till now practically all the valley above Five Sheep Creek, from the creek bed to the cliffs of the Chitistone limestone on the north, is included in them. A large proportion of the claims are patented, and all are the property of the Hubbard-Elliott Copper Co.

The geology of that part of Elliott Creek where copper has been found is simple so far as rock formations are concerned but is complex structurally because of numerous faults, some of them of great displacement, which disturb the normal succession of beds. Most of the creek channel and the lower north slope of the valley is occupied by the Nikolai greenstone, which forms a long, narrow area bounded on all sides by the Chitistone limestone. Outcrops of limestone are not conspicuous on the south side of Elliott Creek, but the bold cliffs high on the mountain slope north of the creek are perhaps the most striking geologic feature of the valley. Thin-bedded Triassic limestone and shale alone accompany the limestone in places. The massive Jurassic conglomerate (Kotsina conglomerate) capping the mountains north of the creek and the tuff and basalt that form the mountains on the south seem to have no connection with the copper deposits. Dikes of quartz diorite porphyry cut both the greenstone and the limestone but are not numerous and, so far as is known, are almost wholly restricted to the north side of the valley.

The greenstone and limestone are not closely folded but are cut by the great major faults on both sides of the valley and by numerous other faults whose displacement is difficult to determine except where they cross the contact. In such places the displacement is not great. Much greater displacement probably occurred along bedding planes or the contact of the limestone and greenstone at several localities. The greenstone, however, is everywhere jointed and fractured. Definite zones of faulting or fracture can be made out and locally have been mineralized by copper-bearing solutions.

The copper deposits are restricted to the Nikolai greenstone and differ little from one another, although the association of copper minerals is not everywhere the same. The deposits commonly consist of either bornite and chalcopyrite or chalcocite and bornite and are accompanied by little or no gangue, although in places some combination of the minerals calcite, quartz, and epidote is present. Quartz and epidote are likely to be present together. Calcite, on the other hand, is most likely to occur alone, although it may be associated with quartz.

The copper sulphides were deposited as irregular veins along fracture planes, either filling cavities or replacing the greenstone, as films and veinlets in sheared greenstone, and as grains disseminated through the greenstone near faults and fractures. There appears to be no good term for describing the knots and network of copper sulphides in the greenstone. Their form depended on the variations of fracturing and shearing that took place in the rock and the way in which they were able to replace it. Some aggregates of the sulphides have sharp, clean-cut boundaries. Others, on the contrary, lack such boundaries and fade away in the country rock.

Evidences of copper, particularly the surface stains of malachite, are numerous and in many places indicate small bodies of mineralized rock that probably have little or no value. The descriptions of properties will therefore be practically restricted to the prospects that in the judgment of the owners held the greatest promise and have been the objects of special investigation. Inasmuch as time was not available for mapping the tunnels and making a close detailed study of all the prospects, the descriptions are incomplete in certain respects. Moreover, as no work has been done on many of the patented claims since the time when patent was granted there is little to add to some of the descriptions that have already been published.[57] The Albert Johnson, Elizabeth, and Goodyear claims are those on which most work has been done.

Albert Johnson and Guthrie claims.—The Albert Johnson claim is on Deception Creek and lies mostly on the east side, although one corner extends over to the west side. On the north of it is the Guthrie claim. The two claims lie end to end and extend in a northwesterly direction, close to the contact of the limestone and greenstone, but do not extend over onto the limestone, which lies along their northeastern boundary. Two tunnels have been started on the Albert Johnson claim. The older is near the limestone and about 1,200 feet above the mouth of Deception Creek. The other is several hundred feet downstream and at a slightly lower altitude.

The rocks near the upper tunnel have been much faulted and are intruded by dikes of diorite porphyry. A few feet above the tunnel is a faulted-in mass of Chitistone limestone separated by a diorite porphyry dike and thin-bedded shale and limestone from the main area of limestone still farther north. Several other faults that displace the greenstone and the sedimentary beds show that the rocks of the locality have undergone much disturbance.

The upper tunnel was driven to the east in greenstone for 48 feet along a fracture zone mineralized with bornite and chalcopyrite, in which bornite predominates. The copper sulphides are associated with quartz, epidote, and calcite and occur as veins and as replacement deposits in the greenstone. The ore taken from the tunnel shows pieces a foot or more in diameter and consists almost wholly of bornite but contains a little gangue or country rock. Some of it shows banded veins of quartz, calcite, and epidote accompanied by bornite and chalcopyrite. Grains of chalcopyrite are scattered through the greenstone near the veins. A winze 15 feet deep was sunk in the tunnel and was continued as two slopes, one 62 feet, the other 28 feet long. The slopes are inclined to the north and follow the dip of the ore-bearing fractures.

About 200 feet west of this tunnel, on the other side of the creek, is a short tunnel on the Guthrie claim. Here the greenstone is shattered and cut by small veins containing bornite and chalcopyrite associated with quartz, calcite, and epidote. The greenstone away from

[57] Moffit, F. H., and Maddren, A. G., Mineral resources of the Kotsina-Chitina region, Alaska: U. S. Geol. Survey Bull. 374, pp. 63–71, 1909.

the larger fractures is cut by films and veinlets of chalcopyrite, without accompanying gangue minerals, which show a rude parallelism but are connected with other films and veinlets so as to form a fine network of the copper mineral. Near the mouth of the tunnel a small vein of epidote and calcite that strikes N. 50° W. and has a thickness of 1 inch cuts a vein of bornite and calcite that strikes N. 30° E. and is of about the same size. It is obvious that the epidote-calcite vein is older than the copper-bearing calcite vein. Evidences of copper are seen on the surface of the rocks between the Guthrie and Albert Johnson tunnels, so that there is reason to suppose that both tunnels are on the same shear zone.

The lower tunnel on the Albert Johnson claim is the tunnel where prospecting is now in progress. It is on the east side of Deception Creek and extends in a northerly direction toward the limestone-greenstone content. Its length, when the tunnel was visited in 1916, was 1,076 feet, but several crosscuts add considerably to the total length of openings. Its course is about N. 25° E. The tunnel mouth is only a few feet from the creek. The tunnel was started to prospect a shear zone thought to extend through the Albert Johnson claim from the Marie Antoinette and to explore the vicinity of the limestone-greenstone contact. At about 300 feet from the tunnel mouth a shear zone was encountered, which carries bornite and chalcopyrite deposited along the fracture planes. Where the ore occurs in veins it is associated with calcite, but where it penetrates the greenstone in grains and small veinlets the calcite is absent. Crosscuts were driven on both sides of the tunnel at this point. That on the east followed a copper-bearing fracture S. 20° E. for nearly 100 feet and then swung to the east. The ore-bearing fractures are cut and displaced by faults later than the ore, so that the ore could not be followed continuously. Apparently the ore-bearing fissures are of two sets, one of which strikes N. 20°–30° W. and the other approximately at right angles to the first set. They are cut by barren fissures, approximately perpendicular to each other, one set of which strikes from north to N. 10° E.

At a point 850 feet from the tunnel mouth the miners encountered a zone of crushed greenstone which was not firm enough to stand and required timbering, though all the remainder of the tunnel is untimbered. Small particles of native copper were found in this crushed rock, the only native copper yet discovered in the tunnel. At 100 feet farther on, or about 125 feet from the end, the tunnel penetrates black limestone and shale. These sedimentary beds are not in their normal position. They are brought here by faulting and are so much crushed and broken that they look almost like dirty coal. No copper was found in them.

Goodyear, Henry Prather, and Curtis claims.—The Goodyear tunnel is nearly half a mile from the mouth of Rainbow Creek and about 300 feet above the west side of the creek, near the boundary of the Goodyear and Henry Prather claims. The tunnel mouth is on the Goodyear claim only a few feet above the creek, but the tunnel was driven west-northwestward so that its two branches would enter both the Henry Prather and Curtis claims. It is in greenstone and has a length of approximately 300 feet. About 200 feet from the mouth veins containing pyrite, chalcopyrite, and bornite, associated with calcite and quartz, cut the greenstone. Pyrite predominates over the chalcopyrite, and bornite is inconspicuous.

Above the tunnel is an open cut on an outcrop of greenstone which has been leached along a zone of fracture and is veined with bornite and chalcopyrite in a calcite gangue. The amygdaloidal greenstone is cut by faults and is much jointed. The most prominent of these faults strike north and dip about 40° W. Another set of less conspicuous faults has a more easterly strike and a lower dip to the northwest. Between two of the north-south faults is a mass of rock of lighter color than the greenstone outside the faults. This lighter-colored rock is sheared or sheeted parallel with the faults and is filled with a great number of thin calcite veins containing chalcopyrite or copper-bearing pyrite and bornite. In the lower part of the cut this mineralized body is between 4 and 5 feet thick and forms a lenticular mass about 20 feet long, bounded by two north-south faults and a northeast fault. The upper north-south fault is not continuous, but the lower footwall fault extends to the north for some distance. On the south this body is much crushed and is filled with iron oxide. It can not be traced farther in that direction than the limit of the cut. Besides the thin veins of copper minerals in the sheeted rock there are small veins of calcite and copper minerals throughout the mass.

Along the strike a short distance to the north and a few feet higher the light-colored copper-bearing rock reappears, but the upper boundary of the mass is the fault which forms the lower boundary of the lower body. The mineralized body has a maximum thickness here of not less than 8 feet. An irregular branching calcite vein containing small horses of the light-colored rock or main ore body reaches a thickness of 14 inches and contains chalcopyrite and bornite. This body of ore continues for a distance of 50 or 60 feet toward the north. These two bodies are portions of a single body included between two north-south faults and cut by later faulting.

Almost directly above the Goodyear claim on the hill slope to the west, not more than 100 feet away, is the open cut on the Henry Prather. Here a north-south fault dips 60° W. and is intersected by two parallel faults striking N. 40° E. and dipping 25°–30° W.

These faults inclose a lenticular mass of rock 30 feet long and 5 feet wide, whose weathered surface is lighter in color than the inclosing greenstone and which is similar in all respects to the ore body of the Goodyear. This lighter-colored rock is impregnated in a similar manner with copper sulphides, and through it runs a vein of coarsely crystalline calcite carrying chalcopyrite and bornite, which are rich in places. The calcite vein has an irregular thickness ranging from 8 to 12 inches and in two places is offset by small faults to a distance of 10 inches.

The main north-south fault may be traced north for about 75 feet and shows much green stain and some sulphides, but the large calcite vein and main ore body end, apparently having been faulted off. Almost 50 feet from the ore body the large fault is intersected by a northeast fault. This also shows copper stain, and both contain small calcite veins with the sulphides.

The similarity in character and appearance of these two ore bodies of the Goodyear and Henry Prather indicate that they are faulted portions of one mass.

A tunnel was started on the Curtis claim, a short distance south of the Goodyear tunnel and higher above the creek. It is 12 feet long and penetrates sheared greenstone, mineralized with pyrite and highly stained with iron hydroxide. Two prominent shear zones cut the greenstone. They have the same strike, N. 15° W., but the more prominent fractures dip 30° W., and the others dip 80° NE. Assays of samples from this tunnel are reported to show both gold and silver.

Elizabeth claim.—The Elizabeth claim is on the hill west of Rainbow Creek and north of the upper camp. Evidences of copper mineralization appear on the east side of Emerald Gulch and have been prospected by several open cuts and a tunnel. The tunnel is approximately 800 feet higher than the camp at the mouth of Rainbow Creek. About 100 feet above the tunnel is a large open cut in much broken greenstone, cut by numerous faults. The three most prominent of these are a vertical fault striking N. 50° W., a fault with high easterly dip striking N. 50° E., and a fault that strikes N. 20° E. and dips 75°–80° W. Veins of bornite, chalcopyrite, and quartz were formed along the fractures in the greenstone, particularly the northeasterly fractures, but have been shattered by faulting which occurred after the copper minerals were deposited. One vein of bornite, lying between altered greenstone and a vein of quartz 6 inches thick, was 3 inches thick. The copper minerals also impregnated the greenstone adjacent to the veins.

Still higher on the ridge and about 200 feet above the open cut just mentioned is a second open cut showing well-developed parallel faults that strike N. 25° W. and dip 60° E. They show no copper.

The Elizabeth tunnel runs in a northeasterly direction and crosses a number of well-defined faults and zones of shattered rock containing copper but does not disclose any large quantity of ore. Bornite and chalcopyrite are the copper minerals and are associated with calcite and quartz in small veins and lenses or impregnate the greenstone without accompanying gangue minerals. The tunnel is several hundred feet long and has a number of crosscuts. A winze in the tunnel was filled with water and could not be examined.

The exposures on the Elizabeth claim appear to indicate a zone of fractured greenstone, mineralized with copper, extending up the ridge in a north-northwesterly course. Copper stains can be traced on the surface for several hundred feet. Both on the surface and in the tunnel the greenstone is much fractured. The faults are marked by a breccia of crushed greenstone, and where distinct faults are not indicated the greenstone blocks are bounded by slickensided surfaces.

Mineral King and Copper King claims.—The Mineral King and Copper King claims are on the south side of Elliott Creek at its head. They lie end to end and with one or two other claims cover most of an area of greenstone between the creek on the north and a precipitous cliff of Chitistone limestone on the south. This greenstone area is a steep, craggy slope leading up to the base of the limestone. It is subject to dangerous snowslides in winter and is so much sheltered from the sun that snow hangs in the gulches late into the summer.

The Copper King claim lies on the west and has been prospected by an open cut a little more than 100 feet below the limestone, or between 300 and 400 feet above the creek. The copper deposit is an intimate mixture of bornite and chalcocite along a shear zone. A little pyrite is present, and besides malachite a blue coating of copper sulphate, chalcanthite, appears in protected places. The shear zone apparently runs parallel with the line of the limestone cliffs above, or about east-northeast, and dips to the south. It has been penetrated by mineral-bearing solutions, which not only have deposited copper sulphides along the fractures but have leached the greenstone adjacent to them and have given it a lighter color than the surrounding country rock. The solutions have affected the greenstone thus to a thickness of about 10 feet at the open cut.

The Mineral King claim is east of the Copper King and is similar to it in geology and the occurrence of copper minerals. Several open cuts have been made on it, two of which have good outcrops of ore. They are about 100 feet apart along a shear zone running N. 35° E. and showing a number of faults that dip 30° S. The greenstone is crossed by vertical joints that strike N. 60° E. and by faults that dip 30° SE. One north-south fault dips 40° E. The copper ore is a mixture of bornite and chalcocite replacing greenstone, particularly along joint and fracture planes. Chalcocite predominates over the bornite in some specimens, so that the ore appears to be all chalcocite, but close inspection reveals the bornite. A gradation from solid sulphides to greenstone can be traced, and it is difficult to tell whether some of the greenstone contains copper except by breaking the rock to get a fresh surface. At one point the mineralized rock has a thickness of about 6 feet and can be traced for four or five times that distance along the shear zone. The boundaries of the body, however, are indefinite.

Swazie claim.—The Swazie claim is on Queens Creek opposite the Copper King. An open cut about 150 feet from the base of the limestone cliffs on the north exposes a mass of shattered greenstone highly stained with iron oxide in contact with an isolated mass of limestone along a vertical north-south fault. The limestone near the fault is stained with azurite and malachite and contains a little pyrite, chalcopyrite, and bornite. The mineralized rock is reported to contain also from $2 to $3 in gold to the ton in addition to the copper.

Copper Queen claim.—The open cut on the Copper Queen claim is about 50 feet west of Kings Creek. It has an elevation of 905 feet above the upper cabin. At the time of visit the cut was nearly filled by the caving of the bank above, so that the face of the greenstone was not exposed. A large mass of the rock, however, which lay at one end was filled with a great number of tiny intersecting veins of iron and copper sulphide, either pyrite or chalcopyrite or both. The greenstone fragments were covered with the green copper coating.

Marmot claim.—A large open cut has been made on the Marmot claim at the base of the limestone between 200 and 300 feet west of Pouch Creek. The greenstone is much broken, and slickensided surfaces are numerous. The most prominent fault planes strike approximately N. 60° W. and are nearly vertical. Small calcite veins carrying a small amount of copper-bearing pyrite occur along some of the openings. A malachite coating was seen in the greenstone but is not prominent along the main fault planes. Bornite was not observed.

Louise claim.—The Louise open cut is on the east side of Rainbow Creek and 50 feet above it, or 390 feet above the upper cabin. The country rock is greenstone and is cut by faults and joints. Slickensided surfaces are common. The best-developed fault planes strike about N. 20° W. and dip 45°–50° W. Small calcite veins, having a thickness in general not greater than 2 inches and containing a little quartz, cross the country rock in all directions. Such veins are more numerous here than in most of the other workings examined. Bornite and chalcopyrite are the copper minerals present, and of the two bornite is the more abundant. They appear in the calcite veins and disseminated through the greenstone. The copper minerals are best developed, however, in the calcite veins and the greenstone adjacent to them. It is difficult to give any definite statement of the thickness of the mineralized zone, which extends parallel with the creek for a distance of about 30 feet horizontally. Above the cut on the steep hill slope green copper stains can be traced for a distance of 150 or perhaps 200 feet.

Lizzie G. claim.—The open cut of the Lizzie G. claim is in the bed of Rainbow Creek only a short distance from the Louise. The greenstone at this place is sheared and plicated, but many of the resulting openings have been filled by infiltration of quartz and calcite. Quartz veins reach a thickness of 2 inches and carry considerable chalcopyrite. Calcite filling is, however, the more abundant, and in places the rock consists of about equal amounts of sheared greenstone and calcite similar to the knotty masses of schist and quartz seen in highly metamorphosed regions. These calcite-greenstone veins, if such they may be called, carry a considerable amount of bornite and chalcopyrite.

Marie Antoinette claim.—Copper minerals are exposed in the Marie Antoinette claim in two open cuts on the top of a narrow ridge adjoining the Elizabeth claim on the northwest. These cuts are within less than 100 feet of each other and show shattered greenstone stained with the oxidation products of iron and copper. There are a number of faults which strike in different directions, and in the open cut on the west brow of the ridge a crushed vein of variable thickness, consisting of calcite and a small amount of quartz, is exposed. The greenstone also contains veinlets of calcite, which follow joint or slip planes and carry the copper and iron sulphides. The larger vein strikes approximately N. 30° W., a direction which would take it somewhat to the south of the other open cut. Near it a small vertical dike of fine-grained diorite from 2 to 2½ feet thick cuts the greenstone.

Leland and Lawton claims.—The Leland and Lawton claims are in the saddle between the heads of Five Sheep and Deception creeks, at an altitude of more than 2,500 feet above the lower cabin. They lie north of the main body of the Chitistone limestone, whose scarp forms the prominent cliff on the southern brow of the spur to the south. This unusual location apparently above the limestone is due to faulting, which brings the greenstone up against the Kotsina conglomerate or rather against the large porphyritic dike which here separates these two formations. On the Lawton claim a fault that strikes N. 30° W. and dips 50°–60° S. is seen between the greenstone on the south and the porphyry dike on the north. The dike here shows a thickness of 30 to 35 feet. Several open cuts have been made in the greenstone and show small amounts of pyrite and chalcopyrite impregnating the rock adjacent to joint or fault planes. Green copper stain and also the copper sulphate chalcanthite were seen in a number of other places. The copper minerals where observed were all within a few feet of the porphyry dike, but any other relation between the two was not evident.

Cliff claim.—The Cliff claim is on the west side of Deception Creek. Here two open cuts have been made at an altitude of 600 feet above the mouth of this stream. The greenstone is cut by numerous fault planes, and slickensided surfaces are frequently seen, but perhaps the most prominent of the planes of movement strike nearly east and dip about 45° N. The green copper carbonate and the oxide of iron stain the greenstone. Small amounts of the copper sulphides also are exposed along joint planes, but no considerable exposure of ore has been made.

Chance claim.—The Chance is the most westerly of the patented claims and includes the prominent point of the limestone cliff which is seen on entering the valley. A small open cut only a few feet below the base of the limestone shows the green copper stain and a little bornite in the greenstone.

Other claims.—A considerable number of claims on Elliott Creek not included in those already mentioned are held by the Hubbard-Elliott Copper Co. Some of them are patented claims; others are unpatented and require assessment work each year. To a certain extent the work required on the unpatented claims has interfered with the rapid exploration of claims like the Albert Johnson and Elizabeth, for it has necessarily diverted attention from them during a large proportion of the working season. On the other hand, it is not possible to work in a place like the lower Albert Johnson tunnel early in the summer, inasmuch as the deep gulch through which Deception Creek flows is then blocked by snow and ice.

All of the Elliott Creek channel from a point somewhere below the lower camp and in addition parts of the mountain slope south of the creek are now covered by claims. The claims south of the creek, except those on the Nikolai greenstone, were staked as a result of excitement over lode gold caused by the discoveries on Benito Creek. (See p. 142.) They are mostly in the area of older rocks belonging to the Strelna formation and were not looked on as favorable for copper. Furthermore, they have not yet afforded gold-lode prospects that give promise of value.

KUSKULANA RIVER.

CLEAR CREEK.

The copper prospects of Clear Creek, frequently referred to by the name Copper Mountain, include 58 claims and are the property of the Great Northern Development Co. Patent had been granted on 35 of these claims at the time of visit in 1916 and was expected on the remaining 23 claims within a short time.

These claims are at the head of Clear Creek. They are reached from the lower camp near the crossing of Clear Creek and the Strelna road by a branch road, somewhat out of repair in 1916, which leads to the upper camp, where the mining is carried on. This road is 3½ miles long and climbs 2,500 feet from the road crossing (altitude 2,612 feet) to the upper camp (altitude 5,134 feet). Most of the claims are in the Clear Creek valley, but part of them extend over the ridge into the Porcupine Creek valley. They cover an area of greenstone (Nikolai) and intrusive coarse-grained granodiorite, which probably represents a later phase of the granodiorite intrusion. The principal area of granodiorite is in the Porcupine Creek valley, but the southwest boundary between the greenstone and granodiorite lies partly on the Clear Creek side of the ridge. Apophyses of the granodiorite, in great variety, from large arms to stringers only a fraction of an inch thick, extend out into the greenstone. In places, particularly in the Porcupine Creek valley, masses of greenstone are included in the granodiorite.

Both the greenstone and the granodiorite are faulted and sheared. Some of the faults are of considerable displacement and probably are to be correlated with faults indicated by the limestone-greenstone contact west of Clear Creek. The shearing of the greenstone and granodiorite probably accompanied the faulting.

The greenstone at the borders of the granodiorite is mineralized with pyrite and chalcopyrite, which occur as veins along fault and fracture planes and as grains, leaves, and small irregular-shaped bits of mineral replacing the greenstone or filling tiny openings along zones of fracture. Pyrite is disseminated through parts of the granodiorite but so far as development work has shown is not accompanied by any great quantity of copper. Magnetite and garnet have been found in greenstone in the tunnels, but the quantity is so little as to escape notice except on most careful observation.

This property has been prospected by three principal tunnels on which considerable work has been done, and a fourth which is expected eventually to become the main tunnel but when examined was only fairly started. The first three tunnels have a total length, as reported by the manager, of 5,661 feet; the fourth is only 175 feet long.

Tunnel No. 1, on the east side of Clear Creek, is 3,000 feet north of the forks, at an altitude of 5,000 feet. It is the second of the tunnels in size and has two branches, each nearly 1,000 feet long. Tunnel No. 3 is on the east side of the creek, a short distance above camp, at an altitude of 5,200 feet. Tunnel No. 2 is about a quarter of a mile north of No. 3 and 300 feet higher. Tunnel No. 3 was started to open on a lower level the ore uncovered in tunnel No. 2, but work on both tunnels was stopped by a disastrous snowslide, which destroyed the power plant and most of the camp. Since then only assessment work has been done on the creek.

Tunnel No. 2 follows in the main a succession of fracture planes that range in strike from N. 30° E. to N. 60° E. and carry the copper and iron minerals. Pyrite and chalcopyrite are present along many of the fracture planes and show their greatest development in a vein about 2 feet thick in a short crosscut 350 feet from the tunnel mouth.

The showing of chalcopyrite and pyrite in tunnel No. 3 is somewhat less than in the upper tunnel, but the geologic conditions, including the trend of the fractures, are much the same. The mineralization took place in a sheeted zone near the granodiorite contact. All these tunnels are perfectly dry except for a short distance near the mouth, and even there most of the water is due to melting snow which drifts into the tunnels in winter.

Tunnel No. 4 is at the forks of Clear Creek, about 800 feet lower than the camp. It exposes no ore but is expected to become the main working tunnel if the property develops into a copper mine.

The copper content of the mineralized greenstone, so far as is now known, is too low to warrant the expectation of developing this property into anything but a mine of low-grade ore to be operated on a large scale by cheap methods, although some of the higher-grade ore in the upper tunnel, No. 2, might be mined profitably in a small way. This is the consideration on which the manager, E. F. Gray, has prospected the ground.

The work on Clear Creek represents the expenditure of a large amount of money and is more extensive than at any other place west of Kennecott in Chitina Valley. Tunneling was carried on in both summer and winter for several years. Electric drills were used in driving the tunnels and were supplied with current from a generator driven by gasoline power. The entire power plant and the principal camp buildings were destroyed by the snowslide previously mentioned, and most unfortunately a number of lives were also lost. This plant may not be rebuilt even if prospecting is resumed, for it is planned to use power generated on Roaring Creek, tributary to Kotsina River. When work is resumed it is also planned to begin experimenting with methods for treating the copper sulphide in the hope of devising a leaching process by which the copper can be extracted economically.

PORCUPINE CREEK.

Part of the claims belonging to the Great Northern Development Co. lie on the Porcupine Creek side of the ridge between Clear and Porcupine creeks. Assessment work to hold the ground has been done on them, but mining operations are much less extensive than in the Clear Creek valley. The work includes open cuts and several short tunnels in sheared Nikolai greenstone. The open cuts and tunnels are in a zone of faults and fractures that strike N. 25° E. and dip about 50° SE. Minute fissures healed with veinlets of malachite and a little chalcopyrite cut the iron-stained country rock. A little gold is reported to accompany the copper.

Three claims at the extreme head of Porcupine Creek are owned by Messrs. Barrett, Young, and Nafsted. These claims adjoin the claims of the Great Northern Development Co. and show the same type of copper mineralization. The assessment work includes two tunnels, one of which was only recently started.

The Blackburn group, belonging to the Alaska United Exploration Co., is on the southwest side of Porcupine Creek, 2½ miles from the Kuskulana. Three tunnels have been driven on the property. The tunnel farthest upstream is 500 feet above the creek and is 75 feet long. It is in fine-grained basalt cut by dioritic dikes, and both the basalt and the dike rock are much shattered. A strong vertical fault near the tunnel mouth strikes N. 25° E. and is almost perpendicular to the line of the tunnel. The broken country rock is mineralized with pyrite and a little chalcopyrite, which gave rise to considerable copper staining.

Nearly half a mile southeast of the tunnel just mentioned are two other tunnels about 900 feet above the creek. One of the tunnels was caved at the time of visit. The other is 75 feet below it in the gulch and is 125 feet long, including its two short branches. It is driven in greatly shattered greenstone, stained with iron oxide and cut by dikes of diorite. Above the tunnel is an outcrop showing stringers of cavernous quartz containing pyrite and stained with iron oxide and malachite, probably derived from chalcopyrite associated with the pyrite.

NUGGET CREEK.

Nugget Creek is an upper tributary of Kuskulana River, which it joins less than half a mile from the place where the main channel of the river emerges from beneath the glacier ice. It heads against Roaring and Peacock creeks and is separated from Roaring Creek by a high pass sometimes used by foot travelers for reaching upper

Kotsina River. Nearly all the creek is above timber line. An automobile road leads from Strelna to Nugget Creek and furnishes transportation for freight and supplies throughout the year. The distance is 18 miles.

Nugget Creek appears to be the place where copper claims were first staked in Kuskulana Valley. James McCarthy, one of the early explorers of the district, came to the creek in 1900 and built his cabin near its mouth. He staked the claims now owned by the Alaska Consolidated Copper Co. and was one of the first white men to see the big copper nugget from which he named the stream. McCarthy Creek, in the Nizina district, also owes its name to him.

Prospecting or mining has been in progress on Nugget Creek for many years, and a large amount of money has been spent in development work. Without doubt much of this expenditure was justified by the copper showing, but the results have been disappointing, so that in 1919 it was decided to stop work and remove all the equipment of value. This has been done, much to the regret of all interested in this district, and apparently no further development will be undertaken. The following descriptions may therefore seem to be more extended than this property warrants, but they are believed to be justified because the exploratory work on Nugget Creek has been more thorough than on any other property in the district and may throw light on the copper deposits in the greenstone.

The Alaska Consolidated Copper Co. formerly held 45 claims in the Kuskulana Valley, most of which were on Nugget Creek and 36 of which are patented. This number, however, includes the Rarus (Copper Queen) group, on the east side of Kuskulana River, which was abandoned in 1915. The claims on which most work has been done are on the east side of Nugget Creek, although the property extends across the creek onto the mountain slopes to the west. Nearly all the work has been done in the lower end of the valley.

The equipment of the mine included a mill furnished with a large and a small crusher, two jigs, and two tables, all operated by a semi-Diesel engine. Air for the drills and the drill sharpener was provided by a compressor and two semi-Diesel engines. A small air hoist was also used. There was in addition an assay office and the necessary buildings to care for men and horses. Freighting was done after the road to Strelna was completed, by two 3½-ton trucks. The total copper production of Nugget Creek consists of two carloads of high-grade hand-sorted ore shipped to the smelter prior to 1916 and 160 tons of concentrates and hand-sorted ore shipped since that time.

The bedrock of the Nugget Creek canyon and of the mountains west of the creek includes tuff, fine-grained basalt, and a subordinate amount of shale and limestone, all belonging to the Strelna formation. The rocks east of lower Nugget Creek are basalt flows, many of them amygdaloidal, belonging to the Nikolai greenstone. Several small areas of Triassic limestone and Jurassic (?) sandstone are present in the upper Nugget Creek valley, but they have no connection with the copper deposits. The greenstone on both sides of the creek is cut by dikes of diorite and related rock. Such dikes are conspicuous in the mountain sides west of the creek, where their light color gives them prominence.

The Strelna formation and the Nikolai greenstone of lower Nugget Creek are separated from each other by a great fault, which brings the older rocks on the west to a position relatively as high as or higher than the Chitistone limestone east of the creek. Other faults of considerable stratigraphic and structural importance cut the greenstones, but with one exception they have no known connection with the copper deposits.

The most promising outcrop of copper ore yet found on Nugget Creek was on the Valdez claim. This claim accordingly has received much attention and has been thoroughly prospected. It lies on the southwest slope of a small round-topped hill and is about a quarter of a mile from the creek mouth. The country rock is amygdaloidal greenstone, which is cut and displaced an unknown amount by a fault that strikes N. 68° E. and dips 80° N. This fault probably meets the much greater fault that follows the Nugget Greek valley only a little way west of the Valdez claim and ends there, for it has never been found in the walls of the creek canyon. The Valdez fault is accompanied by a fault breccia and a gouge that in places is more than 2 feet thick. In places also it splits into two or more nearly parallel faults with a horse of country rock or of vein filling between. Movement occurred along the fault before the copper minerals were deposited and again after they were deposited, the direction of the latest movement being shown by striae that dip about 45° E. Minor faults or fractures, probably branches of the main fault, have nearly the same strike as the main fault. Cross faults striking N. 10°–40° W. intersect the main fault. In most places the hanging wall is amygdaloidal basalt, but locally it is a dense basalt that had no vesicles. The footwall is also seemingly a dense basalt without amygdules, but the rock is commonly so crushed that its character is hard to determine.

The main fault is plainly seen in all levels of the mine and has been traced eastward along the strike for 2½ claim lengths, although there is no evidence to show that the fault exposed in numerous cuts and assumed to be one fault is not really a succession of slightly overlapping parallel faults that differ only a little in strike from the N. 68° E. trend of a fault zone.

Bornite, chalcopyrite, and pyrite are the metallic sulphides in the ore. They are associated with a varying quantity of calcite and appear either in well-defined veins or as grains, films, and small bodies of irregular shape in the sheared and fractured greenstone. In one of the levels chalcopyrite has filled the vesicles of the greenstone.

The original tunnel of the Valdez claim penetrated a vein of white and gray calcite containing bornite and chalcopyrite. It was not exactly perpendicular to the vein, so that the thickness of 24 feet of ore measured along the tunnel wall was somewhat greater than the true thickness. This tunnel seemed to indicate a large vein of bornite and chalcopyrite in calcite, but further work disclosed the fact that the calcite mass at this place was thick in comparison with its other dimensions and did not maintain its thickness either along the strike or in depth. The calcite body, now entirely mined out, was bounded on both sides by faults but lay on the southeast side of the main fault, in some places adjacent to it and in others several feet away. Movement occurred along both faults after the ore was deposited, so that the country rock as well as the vein filling was jointed and crushed. The calcite was broken and in places was granulated. Furthermore, the greenstone near the vein was sheeted parallel to the fault.

Copper minerals, however, are not restricted to veins of calcite along the fault. Copper continues in depth to the limit of the present workings—that is, to a point 420 feet below the outcrop. Bornite diminishes from the surface downward and disappears at the 105-foot level but, it is stated by the manager, reappears lower down. Below the 105-foot level pyrite and chalcopyrite are the prevailing minerals at least as far as the 300-foot level. The metallic sulphides are accompanied by calcite at all levels, but in places the quantity is small and at no other place has any mass of calcite like that at the surface been encountered. The calcite veins were formed only locally, and furthermore the original inequalities in thickness of the calcite ore veins have been increased by faulting after the ore was deposited.

Development work (fig. 7) on the Valdez claim includes about 4,000 feet of excavation represented by adits, shafts, drifts, and crosscuts. A shaft 160 feet deep was sunk from the outcrop to the main working or Lucky Boy tunnel, and from it levels were driven at 35, 55, and 105 feet below the surface, but the part of the shaft above the 55-foot level was destroyed by stoping out the ore near the surface. A series of winzes, drifts, and crosscuts below the Lucky Boy tunnel carried the workings to a depth of 420 feet below the outcrop. This exploration demonstrated that the best ore was that at the surface, and the failure to find it continued in the lower levels led to the abandonment of the mine.

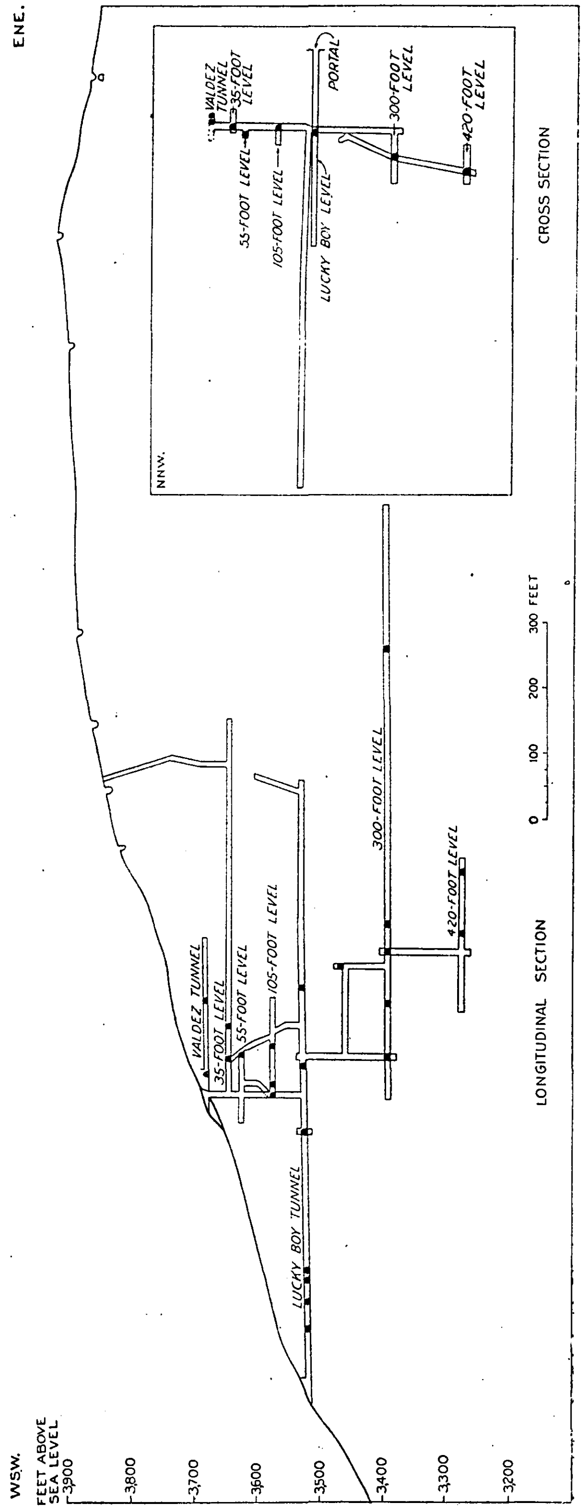

FIGURE 7.—Projections of mine openings on Valdez claim, Nugget Creek.

A little work was done along the fault east of the Valdez claim. The bedrock on both sides of the fault is amygdaloidal greenstone, cut at one place, 200 yards east of the Valdez shaft, by a dark porphyritic dike containing large crystals of hornblende. In places the greenstone adjacent to the fault is leached for a foot or more and has a lighter color than that farther away. Several open cuts and short tunnels show copper sulphides, either bornite and chalcopyrite, or chalcocite and bornite, accompanied in some places by calcite and quartz, in others by quartz and epidote. The quantity, however, is not sufficient to divert attention from the Valdez claim. Work has also been done on other claims, some east and some west of Nugget Creek, but has not given much encouragement for prospecting.

The large copper nugget for which Nugget Creek was named lies in the bed of the creek a short distance above the camp and was discovered in 1900 by A. C. Spencer, of the United States Geological Survey. It is 7 feet long and about 3 feet wide. Its greatest thickness is 12 inches, but the average thickness is less than half that. Few of the photographs give a clear idea of its shape, for most of them are taken with part of the nugget under water (Pl. XIX, *A*, p. 39). The creek gravel near the big nugget contains numerous small nuggets of copper ranging from shot to pieces that weigh several pounds. Although native copper has been found in the greenstone of Nugget Creek, no such large pieces as those in the creek are known in their bedrock source.

FINCH GROUP.

The Finch or Big Horn group of claims is on the southwestern front of the mountain between the forks of Kuskulana Glacier. It belongs to the United Copper Exploration Co. and includes ten claims, one of which is fractional. It lies without the mapped area but close to it.

A trail leads from the old McCarthy cabin on Nugget Creek to a place on the west side of Kuskulana Glacier opposite the point of land between the glacier forks and thence crosses the west branch of the glacier to a well-constructed cabin on the point, from which another trail climbs the ridge to the copper-bearing outcrops. The total length of the trail from Nugget Creek to the cabin is about 4 miles, of which 1 mile is over the gravel-covered glacier.

The country rock is greenstone (Nikolai), much faulted and otherwise fractured, and has been subjected to the action of circulating waters, as may be seen plainly in the leached rock adjacent to fissures.

The principal showing of copper is 1,300 feet above the glacier, on the south brow of the ridge. It is a large disklike mass of granular bornite, chalcocite, and quartz, about 13 feet in diameter and one-quarter as thick, which lies against the much shattered bedrock and, although in place, appears to be faulted off from an ore body not elsewhere exposed (Pl. XIX, *B*, p. 39). The plane of the disk strikes N. 20° E., but the deposit evidently belongs to a prominent zone of faults that strike N. 40° E. and dip at a high angle to the east.

A tunnel about 40 feet long was driven beneath the disk, perpendicular to its strike, and exposed a little ore of the same kind immediately below the disk. A deep open cut or trench more than 50 feet long leads to the tunnel. A second tunnel, 30 feet long, in which a shallow shaft was sunk, is a few feet northeast of the first but discloses no ore. Numerous faults are shown in the open cuts and tunnels. The strongest of them either approximate the strike of the zone of fissuring, N. 40° E., or are perpendicular to it. One strong fault with east-west strike was observed. As a result of the faulting and of weathering all the rock exposed by the tunnels is shattered and stained with iron oxide. This unusual body of copper ore does not resemble any other body in this district known to the writer. Its peculiar characteristic is the granular texture of the ore, but the form of the body itself is notable. It crops out in a place where the greenstone is highly fractured, possibly as a result of the intersection of principal fissures of the shear zone by cross faults.

An open cut 100 feet northeast of the tunnel shows a series of distinct vertical fractures striking N. 40° E. that doubtless belong to the shear zone, but little or no copper is present. About 100 feet to the southwest the shear zone is cut by a narrow dike of dark basic rock striking northwest and resembling the surrounding greenstone.

Another tunnel was begun near the end boundary between the Whistler and Big Horn claims, 200 feet lower than the ore body just described and S. 57° W. from it. It starts on a well-defined vertical fault and runs in a northeasterly direction but branches 20 feet underground into two parallel tunnels. The total length is 75 feet. On the east side of the tunnel mouth is a fault with a strike of N. 60° E. and a high easterly dip. It shows iron-stained gouge and crushed greenstone. On the west side of the tunnel mouth is a fault striking N. 20° E. and another striking N. 10° E. Both dip about 50° E. and from the iron-stained talus on the hill above them appear to have approximately the direction of the main fault zone.

In the face of the left-hand branch of the tunnel is a small vein of bornite and quartz striking N. 70° E. Other fractures containing quartz in short lenslike veins have strikes ranging from N. 70° E. to 90° and are cut by north-south fractures, one of which in the right-hand tunnel has a good gouge. Several tons of ore at the tunnel mouth is ready for shipment and contains pieces showing that the high-grade copper-bearing veins attain a thickness of at least 10 inches.

Still another tunnel has been driven on the Whistler claim. It is S. 30° W. from the tunnel last mentioned and is 150 feet lower on the ridge. If projected it would pass under that tunnel. Its length is approximately 400 feet, but it discloses no ore.

A number of open cuts have been made on different claims of the Finch group, and one or two short tunnels, little more than open cuts, were started. Native copper is reported to have been found at one of these places. Although this group of claims is almost surrounded by the glacier, it is doubtful if the ice would offer serious difficulties to the transportation of ore, for the gravel-covered surface affords very good traveling except near the western edge of the glacier.

MAYFLOWER CLAIM.

The Mayflower claim is on the southeast side of Kuskulana Valley 2½ miles above the lower end of the glacier. This claim, with one or two adjoining claims, has been staked for a good many years and is now controlled by James McConnell and Gus Johnson, although there are or have been others interested with them.

The country rock is greenstone (Nikolai), into which have been faulted small masses of the Chitistone limestone, such as the one that caps the mountain top above the claims. It is evident that these rocks have been much disturbed, for faults are numerous and are particularly noticeable along the contact of greenstone and limestone, where the conditions are most favorable for recognizing them. The claims are on the west side of a prominent gulch opening into the main Kuskulana Valley just south of the place where Kuskulana Glacier bends to the east.

The principal showing of ore is in a steep, narrow tributary gulch at a point between 1,000 and 1,100 feet above the glacier. A zone of fracture along a major fault that strikes N. 50° E. and dips 75° NW. gave rise, through erosion, to the small gulch and contains the copper minerals.

The ore exposed is bornite and a minor proportion of chalcocite in a gangue of quartz. Considerable epidote is associated with the quartz and copper minerals. The ore commonly has a banded structure and fills parallel fractures in the greenstone or replaces the greenstone altogether. Its place of greatest development is near the intersection of a prominent fault striking N. 50° E. with one that strikes north and dips 60° NW. In the face of the open cut a minor fault striking N. 50° E. like the main fault but dipping southeast instead of northwest connects the two faults just mentioned. All three faults are mineralized, but the fault with N. 50° E. strike and northwest dip shows most mineralization. About 12 inches of high-grade ore is exposed along this fault in the open cut. The connecting fault shows about 10 inches of good ore, and the north-south fault shows less. About 25 feet east of this open cut is another well-marked fault striking N. 40° E. and dipping 65°–70° SE. No ore was seen in it. The principal ore body extends up the bed of the gulch a vertical distance of 60 feet, to a point where it is cut off by a southeastward-dipping fault along which there is no copper mineralization. Bornite extends all the way up to this fault, but minor faults later than the ore interrupt the vein in places. No attempt was made to trace the ore higher in the gulch, owing to the steepness of the slope and the difficulty of getting over the cliffs. The ore deposit is distinctly a vein deposit. No bornite was seen disseminated through the greenstone, but small gash veins, parallel to the main vein yet having no visible connection with it, were displayed in the open cut.

A tunnel was started a little south of the gulch and 300 feet below the open cut to undercut the ore body exposed above. It has a length of 75 feet and shows quartz veins with north-south strike in the greenstone. Numerous veins of quartz and epidote are exposed in the greenstone near the tunnel and in the cliffs between the tunnel and the open cut.

PIERSON CLAIM.

An open cut and a short tunnel, now caved, represent the work of prospecting on a claim belonging to Oscar Pierson and others in a small gulch half a mile below Kuskulana Glacier. At this place, which is a little more than 500 feet above the gravel bars of Kuskulana River, the Chitistone limestone and Nikolai greenstone are separated by 30 feet of fine-grained light-colored latitic intrusive. The contact of the greenstone and the intrusive rock is a fault that strikes N. 60° E. and dips 50° E. A zone of crushed rock, from 2 to 3 feet thick, marks the fault and shows copper staining. Free gold is reported to have been found in this place.

TRAIL CREEK.

A group of 14 claims on Trail Creek was patented by the London & Cape Co. in 1909. The claims are on the mountain between Trail and MacDougall creeks and extend to its top, where the principal outcrops of the copper minerals are exposed. As may be seen from the geologic map (Pl. III, in pocket), the country rock of this vicinity is granodiorite. It is much fractured and weathers into angular fragments of small size rather than into blocks. This fracturing in places has been favorable for the circulation of mineralized solutions, which deposited iron and copper sulphides. A number of open cuts on the crest of the hill show small quantities of sulphides, chiefly pyrite, and copper staining. The principal work of development, however, is a tunnel 245 feet long, 2,300 feet above Kuskulana River, and 500 feet below the top of the ridge. It was started in the expectation of exposing an ore body beneath the ridge but was not driven that far and is reported to contain no copper. It was closed at the time of the writer's visit. A steep trail with numerous switchbacks leads from Trail Creek to the tunnel and thence to the ridge. Its upper part, however, is now almost obliterated. No work has been done on the property since the claims were patented.

MACDOUGALL CREEK.

MacDougall or Bigfoot Creek is on the southeast side of Kuskulana River, opposite the mouth of Clear Creek. Although it is more often called by the name MacDougall the claims on it are recorded as being on Bigfoot Creek. The stream is about 3 miles long and in its upper part occupies a hanging valley wholly above timber line. Only the lower part of the stream is represented on the topographic map. The upper valley looks out into the main Kuskulana Valley over a well-defined bench approximately 800 feet higher than the river bottoms but is shut in by high mountains on all other sides. All the mineral prospects are in the upper valley and are the property of the Chitina-Kuskulana Copper Co., of which Angus MacDougall, who staked the claims and organized the company, is manager. The lower main camp on the bank of Kuskulana River is easily reached from the Berg Creek road by a wagon road about 1 mile long over the level gravel bars of the river, and from the camp a pack trail leads up into the MacDougall Creek valley. The other camps have been built in the upper valley, one near the west end 1,200 feet above the lower camp, the other at the east end 1,800 feet above the lower camp. Good log cabins were erected at both places.

MacDougall Creek flows for most of its length over granodiorite country rock, but where the mineral deposits are found its southern valley wall is made of Jurassic conglomerate, sandstone, and shale, the Chitistone limestone, and the overlying Triassic shales (Kuskulana formation). Only the granodiorite and the Jurassic sedimentary deposits appear on the geologic map.

The property of the Chitina-Kuskulana Copper Co. includes 21 claims, of which 5 are mill sites and 16 are lode claims. Exploratory work on the property has been done chiefly on the War Eagle and Calcite claims.

The tunnel on the War Eagle claim, shown on the geologic map, is 350 feet above the middle camp and 200 feet below the base of the Jurassic sedimentary beds. Its altitude above the sea is 3,700 feet. The tunnel is driven for about 100 feet in a south-southeasterly direction in a white silicified limestone, which might be mistaken for an altered fine-grained igneous rock, broken by numerous joints and slips near which the limestone is mineralized. At about 25 or 30 feet from the tunnel entrance a dark, heavily mineralized zone or dike from 8 to 12 inches thick is exposed. It contains pyrite and chalcopyrite or copper-bearing pyrite and is stained green by copper oxidation products.

The copper and iron sulphides are contact-metamorphic minerals resulting from the intrusion of the diorite but are not the most abundant minerals of the kind in this locality. Bodies of magnetite locally associated with much garnet crop out at several places near by. The largest body exposed to view is on the hill slope almost directly above the War Eagle tunnel a little below the Jurassic conglomerate. It is exposed for a width of 25 feet and is separated by a vertical north-south fault from a fine-grained gray igneous rock, on the west, consisting almost entirely of feldspar but containing a little epidote. The magnetite extends to the base of the conglomerate a short distance away but stops abruptly there. Magnetite is exposed at other places near this locality and farther around in the creek valley, but the lower slopes of the mountain are so thickly covered with loose rock and vegetation that the writer did not get a clear idea of its relation to the inclosing rock. From the fact that rounded pebbles of the magnetite have been found in the conglomerate at the base of the Jurassic sedimentary beds it is believed that the magnetite deposits were formed before the sediments were deposited.

The Calcite tunnel is at the head of MacDougall Creek near the top of a narrow ridge between MacDougall and Trail creeks. Its altitude is approximately 4,800 feet above sea level, 500 feet above the upper camp, and 1,600 feet above the middle camp. The tunnel follows the contact of silicified limestone and a light-gray medium-grained granodiorite for about 600 feet. This contact is a fault contact and originated in a movement by which the Chitistone limestone and the overlying Triassic shales (Kuskulana formation) were thrust northward over the Jurassic sedimentary beds. The fault zone in general strikes N. 75° W. and dips 25°–30° S., but in the tunnel the dip is 45° S. All the rocks in this vicinity are fractured and sheared and locally are mineralized along the fracture planes with pyrite and chalcopyrite. Copper staining is abundant.

Power for drilling at the War Eagle tunnel is furnished by current brought from the main camp on Kuskulana River, where a steam engine and electric generator are installed. Wood cut near by on the river flats is used for fuel to generate the steam. The transmission line extends from the river to the middle camp, near the War Eagle tunnel, but not to the upper camp. The equipment at the middle camp includes a compressor and air tanks, power drills, jack hammers, and drill sharpener. Hand drills were used at the Calcite claim for driving the tunnel, but a gasoline engine and blower furnished air for ventilation.

A separate company, closely affiliated with the Chitina-Kuskulana Copper Co. but separately organized and called the Mount Wrangell Copper Co., owns the Copper Queen claim, formerly known as the Rarus.

COPPER QUEEN CLAIM.

The Copper Queen claim, owned by the Mount Wrangell Copper Co., is on the southeast side of Kuskulana Valley about half a mile southwest of MacDougall Creek and adjoins the War Eagle group, previously described. It was prospected by a tunnel 1,200 feet above Kuskulana River, at an altitude of 3,200 feet. The claim formerly belonged to the Alaska Consolidated Copper Co. but was given up in 1915 and was restaked by other persons in the following January. Nearly all the work in the tunnel was done by the former owners.

The country rock includes limestone, greenstone, and intrusive rocks, all of which are much altered chemically. The limestone in particular is silicified and in places is garnetized. These rocks are faulted and crushed and are so mixed together that it is impossible, with the outcrops available, to work out the details of structure.

The tunnel, whose course is S. 15° E., follows a succession of poorly defined faults for 433 feet. For the first 100 feet it passes through silicified limestone. It next enters a dark-colored faulted and broken rock that is called porphyry by the miners but is probably a modified greenstone and continues in this rock till it encounters the garnet rock, 22 feet from the tunnel face. A number of porphyritic intrusives cut the greenstone. The contact of the limestone and greenstone is a fault breccia forming a zone of broken rock and gouge with a course N. 60° E. At a point 256 feet from the entrance a crosscut, 50 feet long, was driven to the right. Just beyond the crosscut a fault striking N. 20° E. crosses the tunnel, and beyond that lies the ore body. The ore-bearing greenstone includes an intrusive or infaulted mass of basalt porphyry showing large crystals of hornblende and augite. Nearly all the greenstone is mineralized with pyrite, but the heavy mineralization took place in the rock between the crosscut and the garnet rock, where magnetite, pyrite, and chalcopyrite are present in considerable quantity.

Good exposures of the country rock above the tunnel show a well-defined zone of fracturing that cuts across limestone and greenstone and extends S. 15° E. to the base of the conglomerate, 600 feet above the tunnel mouth. The limestone crossed by this zone is silicified, and the greenstone is highly stained with iron and copper.

BERG CREEK.

The area of contact-metamorphic rock in which the Copper Queen and War Eagle claims, previously described, are situated may be traced westward from MacDougall Creek to the place where all bedrock is covered by the gravel deposits of Kuskulana Valley. Most of the area in which these rocks are exposed southwest of Berg Creek is claimed by the North Midas Copper Co. The claims, however, are often connected in the Kuskulana district with the name of Ole Berg, who first prospected them.

The geology of this locality differs somewhat from that of the area to the northeast, in that the prevailing rocks are limestone (Chitistone) and diorite porphyry. Dark-colored igneous rocks, basalt and basalt porphyry, are less common. Many intrusive masses of diorite porphyry are included in the limestone, and the limestone adjacent to them is either silicified or altered to a highly garnetiferous rock having little resemblance to the original limestone. Numerous faults and fractures made the rocks a favorable place for the circulation of water and at a later time still further complicated the structure of the mineralized areas.

The metallic minerals of the locality are magnetite, pyrite, and chalcopyrite, which occur chiefly as veins in the diorite porphyry and the dark-colored igneous rocks and locally carry gold and silver. Pyrite and chalcopyrite are distinctly more abundant than in the part of this contact-metamorphic area between Berg and MacDougall creeks.

Five tunnels have been started on the property. Of these Nos. 1, 2, and 3 are on copper prospects. Nos. 4 and 5, although begun on showings that indicated copper, opened up a vein that is now valued for its gold and silver content and is described on page 143. Tunnel No. 1 is near Berg Creek at an altitude of 3,000 feet above the sea, or 1,000 feet above Kuskulana River. Tunnel No. 2 is 500 feet southwest of No. 1, and No. 3 is about 1,000 feet southwest of No. 2. The altitude of tunnel No. 2 is 3,250 feet; that of No. 3 between 50 and 75 feet less.

Tunnel No. 1 is about 1,200 feet from Berg Creek and is 480 feet long. Its course as given by the compass is S. 5° E., but compass readings may be subject to a considerable error due to the quantity of magnetite near by. The country rock penetrated by the tunnel includes altered limestone, dark-colored fine-grained igneous rock, and porphyritic intrusives. A section of the tunnel between points 250 and 300 feet from the tunnel mouth includes a zone of much disturbed country rock where several faults, by which masses of silicified limestone were dragged into the igneous rocks, are present. At 250 feet from the tunnel mouth is a fault of particular prominence, marked by 3 inches of gouge, which strikes N. 35° E. and dips 50° W. The adjacent rock is mineralized and shows pyrite on the hanging wall and magnetite on the footwall. South of the fault are crushed porphyry and basalt containing magnetite, pyrite, and chalcopyrite. The magnetite is mostly near the floor, but masses of it are faulted into the crushed porphyry of the roof. The dark fine-grained basalt exposed in the last 10 feet of the tunnel is mineralized with pyrite.

Tunnel No. 2 is a winding tunnel 140 feet long, driven in a general southerly direction, and has a short crosscut on each side 100 feet from the mouth. The country rock consists of coarse-grained granodiorite, porphyry, and limestone, much faulted and fractured. A fault striking N. 25° E. and dipping 60° E. crosses the tunnel at the crosscut.

The copper deposits are on the hanging-wall or southeast side of the fault and consist of pyrite and chalcopyrite cut by small parallel veins of chalcanthite. They are cut off on the south by a vertical fault striking N. 75° E. A parallel fault 8 feet distant on the north forms the north wall of the crosscut. The crosscut consequently lies between the two parallel faults. That part of the crosscut on the west side of the tunnel is in barren ground; but that on the east exposed good ore, which is now partly mined out. A shallow winze was sunk in the eastern crosscut but was filled at the time of visit.

Tunnel No. 3 is nearly 500 feet long and trends a little south of southeast. For the greater part of its length it is in igneous rock—basalt and intrusive diorite porphyry. Near the middle of the tunnel is a mass of silicified limestone and also a mass of coarse-grained diorite porphyry bounded by southward-dipping faults on both sides. The limestone is not mineralized, but the igneous rocks nearly everywhere contain pyrite and chalcopyrite.

An open cut on the south side of the gulch south of tunnel No. 3 exposes the contact of limestone on the southeast with a rock on the northwest consisting largely of garnet. These rocks lie on opposite sides of a fault zone nearly 15 feet wide, which strikes N. 40°–50° E. The garnetiferous rock contains pyrite and chalcopyrite and is stained with copper.

Several open cuts have been made along the gulch between tunnels Nos. 1 and 4. They expose much magnetite with which pyrite and chalcopyrite are associated and indicate a zone of faulting extending in a northeasterly direction.

GOLD DEPOSITS.

Gold, as compared with copper, has held only a secondary interest among the prospects of the Kotsina-Kuskulana district. In only a few places has it been found in quantity sufficient to attract more than passing attention, and nowhere has it been mined profitably.

There are in the district, however, at least two promising prospects in which gold is the most valuable or the predominant valuable metal and several prospects that contain gold in addition to copper and that have been mentioned in the description of the copper deposits.

BENITO CREEK.

Benito Creek is a small stream flowing into Kotsina River from the southwest slope of the ridge between Elliott Creek and the Chitina Valley. It is crossed by the horse trail from Strelna to Elliott Creek but at certain times of the year is difficult to reach because part of the trail is very wet and soft. The direct distance from Strelna is 9 miles; the distance by trail is between 1 and 2 miles farther. Spruce in the vicinity extends up to an altitude of 3,000 feet above the sea, or about 600 feet higher than the Benito Creek camp, and is of fair quality, so that timber suitable for most mining needs is available close at hand. Most of the creek is within the area of glacial deposits covering the floor of Chitina Valley, from which it results that outcrops of bedrock are few and are found principally along the creek bed. So far as is known, however, the country rock consists of altered igneous and sedimentary rocks belonging to the Strelna formation.

A gold-bearing vein was discovered on Benito Creek in 1913 by J. C. Canning, and at the time of the writer's last visit in 1919 it was being prospected by Mr. Canning and his partner, Benito Centino. The original exposure is a white quartz vein 3 feet thick, which crops out in the creek bed at an altitude of 2,400 feet. This exposure and others near by are now covered by five mining claims arranged in the form of a letter H, with the cross bar extending down the creek from the discovery point. The country rock inclosing the principal vein is in some places coarse diorite and in others a dense altered basalt sheared parallel to the vein, which strikes N. 30° W. and dips 70°–75° E. The vein itself is well defined for nearly 600 feet by open cuts made by sluicing away the overburden and by a line of five shallow holes which were put down to the vein and one of which penetrated it to a depth of 15 feet. Although the creek and the morainal deposits are not deep, the sinking of these holes was accomplished with some difficulty because of water, which flows along the bedrock surface. This difficulty was partly obviated by building a dam and automatic boomer on the creek above the vein and sluicing away the loose material. In this way two cuts ranging in depth from 2 to 25 feet were made. They exposed a complex of sheared and altered rocks, including fine-grained basalt intruded without distinct boundaries by dark coarse-grained diorite containing conspicuous hornblende crystals.

The gold-bearing vein is in most places about 30 inches thick but ranges from 2 to 3 feet. It consists of quartz with a subordinate quantity of calcite. The metallic constituents are pyrite, arsenopyrite, chalcopyrite, silver, and free gold. In most places the vein is fractured and much oxidized, yielding a rusty, cavernous quartz mass in which the free gold appears. Stains of azurite and malachite are conspicuous on fresh surfaces. Many handsome specimens of free gold in quartz from this locality were made by dissolving the calcite gangue so as to expose the gold. The largest piece of gold obtained in this way was valued at $50. Such specimen ore is now uncommon, and most of the ore shows no gold to the eye.

Nearly 100 feet downstream from the principal vein, just described, another quartz vein crops out on the left-hand side of the creek. It strikes N. 10° W. and stands vertical. This vein is also much weathered and contains arsenopyrite and a shining black metallic mineral believed to be specular hematite. Still farther downstream, on one of the claims lying across the creek, is a vein of shattered rusty quartz, 8 to 9 feet wide, containing arsenopyrite and pyrite. Several holes were sunk on it but without particularly encouraging results.

The owners of these claims have not had the means to prospect the ground on an extensive scale and have had to work elsewhere to earn the money to carry on the prospecting that has been done. It is unfortunate that the real value of the property has not yet been determined.

BERG CREEK.

The mining claims of the North Midas Copper Co. (see also p. 140) are on the southeast side of Kuskulana River and extend for nearly a mile along Berg Creek, from the mill site near the river onto the mountain slope south of the creek. They are connected with the Nugget Creek road to Strelna by a branch road which leaves the main road half a mile above Squaw Creek and crosses Kuskulana River by the new Government bridge 1 mile above the mouth of Squaw Creek. From the bridge the road follows first the foot of the bluff and next the gravel bars of the river to the mill on the low terrace overlooking the river a short distance north of the place where Berg Creek reaches the river flats. This road has been in use since 1919 for automobile travel.

The mineral holdings include 18 lode claims, 4 placer claims, and 1 power site. Ole Berg made the original lode locations about 1907 and has been connected with the property as owner or manager since that time. These first locations were on mineralized veins whose valuable content was thought to be copper, and until 1916 prospecting was done in the expectation of developing a copper mine rather than a gold or silver mine. This earlier work is described on page 140, in the section devoted to the copper prospects. In 1916 the tunnel known as No. 4 intersected a vein of sulphide ore which contains a considerable content of gold and silver and which since that time has had considerable development work done on it. The copper-bearing veins have meantime received less attention.

A mill with a capacity of 20 tons a day was built in 1918 on a gravel terrace near the river and is connected with the mine by a cable tram 4,600 feet long and having a present capacity of 5 tons an hour. Power for the mill has been furnished by Berg Creek but proved to be insufficient, so that a Diesel engine was being installed at the time of visit and was expected to be in operation in 1920. Local timber at the mill was available for building and general mining purposes and was used in the construction of the mill buildings and tram towers and also for fuel during a short time while the mill and mine were being run with current generated at the plant on MacDougall Creek. Only a short mill run was made in 1919, for the tram was not completed till late in summer, after the high water in Berg Creek was passed. The production for that year was therefore only a few ounces of silver and gold.

The mineral-bearing veins southeast of Berg Creek are near the boundary between an area of dioritic rocks on the north and one of Triassic limestone on the south. These areas are not sharply distinguishable from each other, for between them is a complex in which limestone bodies, more or less altered and surrounded and intruded by igneous rocks, form an irregular narrow zone not readily assignable to either area. The igneous rocks in the vicinity of the mine workings show a variety of phases. They probably are all derived from a parent granodiorite magma but vary in color, texture, and mineral composition. This is shown well in the mine workings, where the adit walls reveal a rather bewildering succession of changes from one kind of intrusive rock to another. The prevailing rocks are a dark-gray or greenish-gray fine-grained diorite and a light-gray, conspicuously porphyritic granite. These rocks grade into one another without well-defined boundaries.

The limestone is prevailingly a hard white fine-grained limestone, in places silicified, and with little doubt owes its present condition to the alteration of the original Chitistone or overlying Triassic limestones by the intrusion of the igneous rocks associated with it. The zone of contact between the two areas of igneous and sedimentary rocks is also a zone of pressure and extensive movement, so that the rocks are ground together and cut by numerous faults of widely differing strikes and dips. Some of these fractures have been filled with metallic minerals that are plainly of contact-metamorphic origin.

The vein now being exploited fills a well-defined fissure cutting the dioritic intrusive. Two adit tunnels (fig. 8) were driven to it and were connected by drifts with a chute for ore and a loading pocket on the vein. The lower or main adit is 2,800 feet above sea level, or

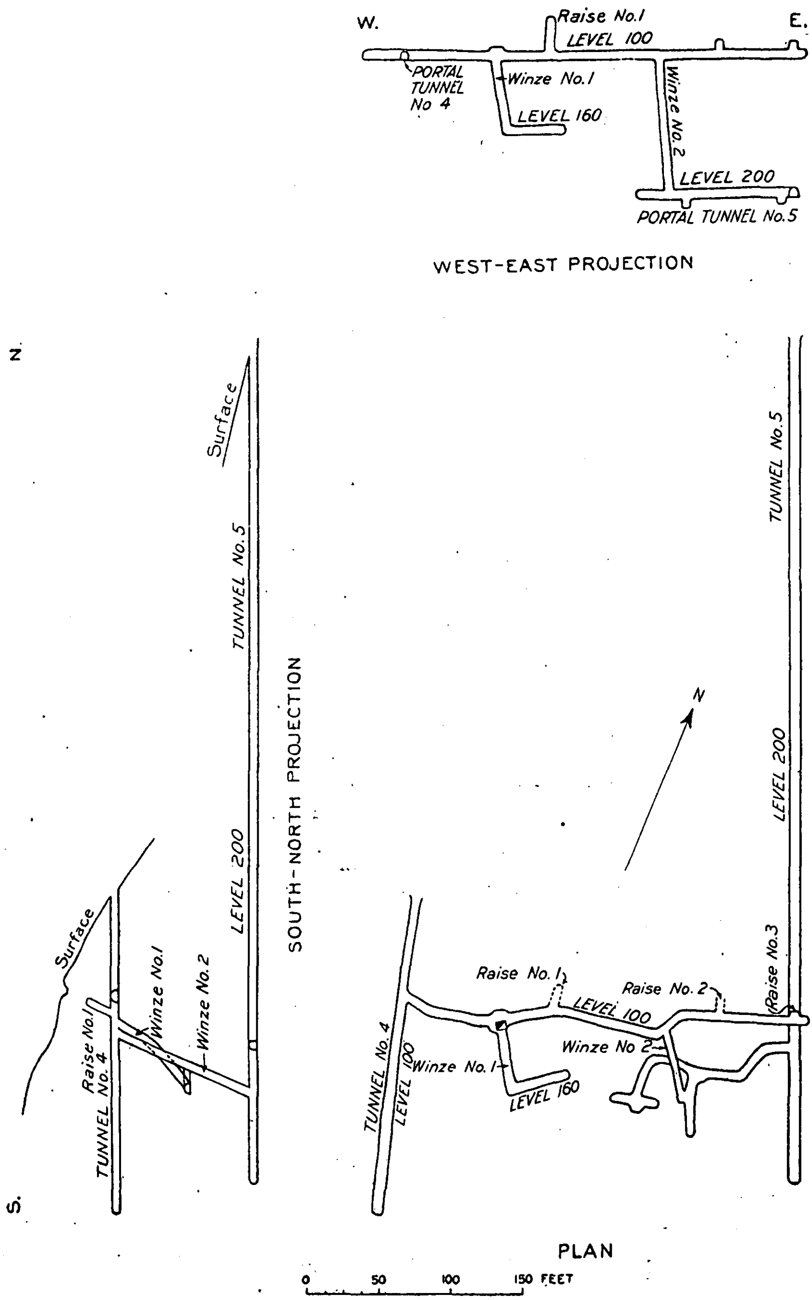

FIGURE 8.—Plan and projections of the mine openings at the North Midas Copper Co.'s gold-silver mine on Berg Creek.

800 feet above Kuskulana River, and is about 100 yards from Berg Creek. The entrance to the other adit, tunnel No. 4, is 450 feet in a south-southwesterly direction from the main adit and at an altitude 100 feet higher. The vein strikes about N. 70° E. and dips 45° S.,

into the mountain, but shows local variation from this dip. Without doubt the vein extends beyond these limits, but its surface croppings are concealed by the vegetation that covers the smooth mountain slopes, and no attempt has been made to uncover them by cross trenches or pits.

The vein has a banded structure and consists of quartz and a very subordinate amount of calcite in which are disseminated iron and copper sulphides, principally pyrite and chalcopyrite. Weathered pieces of the ore show the iridescent hues of the copper sulphides, but the quantity of copper is small. Considerable chemical alteration has taken place in the country rock adjacent to the vein filling, yet little dissemination of the metallic minerals through the country rock was noticed.

The value of the ore lies in the silver and gold accompanying the iron and copper sulphides. The silver and gold appear not to have even an approximately uniform quantitative relation to each other except that silver predominates, for different parts of the vein have shown a silver content ranging from twice to four times that of the gold. The quantity of silver and gold is greatest in the more oxidized parts of the vein, from which an assay of over $450 to the ton has been obtained. The average content of the ore, however, is much smaller than that. No studies were made to determine the form in which silver and gold are present in the vein. It is supposed that they were brought in solution with the iron and copper sulphides and were deposited with them. Chemical tests made by the engineer at the mill laboratory showed the presence of tellurium in the ore, but there is no evidence that the gold and silver formed chemical combinations with it.

OTHER VEINS.

Several other gold-bearing quartz veins have been staked in the vicinity of Benito Creek, but so far as the writer knows they have not shown so good indications of value as the Canning-Centino prospect. One such vein is on Benito Creek and is possibly the extension of the Benito Creek vein. Another is at the crossing of the old Elliott Creek trail and Loraine Creek, a little outside the mapped area. Still another is on the south side of Elliott Creek a little distance above Castle Creek, where a short tunnel was driven in the Nikolai greenstone along a quartz-calcite vein striking N. 25° W. and dipping at a high angle to the east. This vein follows a prominent fault with slickensided surfaces and horizontal striations that show the fault movement to have been in that direction. It is mineralized with pyrite and was reported to contain gold.

Assays of $2 and $3 to the ton are also reported from copper ores on a claim on Rainbow Creek, on the north side of Elliott Creek.

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